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DEVELOPMENT AND APPLICATION OF METHODS FOR EVALUATION OF HURRICANE SHELTERS

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science in Civil Engineering

in

The Department of Civil and Environmental Engineering

by
James P. Gregg
B.S. Louisiana State University, 2002
May 2006

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ABSTRACT

With the population of hurricane prone regions increasing, it has become more difficult to evacuate entire communities, increasing the need for hurricane shelters in coastal areas. Community officials generally use American Red Cross Standard ARC 4496 to evaluate the suitability of buildings for use as shelters. ARC 4496 uses a least-risk process that evaluates many building and site characteristics. However, it does not address characteristics of the approaching storm and does not provide insight to the expected hazards and performance of the facility under different hurricane conditions.

A new method for evaluating facilities for use as hurricane shelters is proposed. Following a performance-based approach, shelter suitability analysis is conducted for a range of different hurricane scenarios. Storm variables considered include Saffir-Simpson hurricane intensity and storm track. This new method provides information for more efficient and effective sheltering decisions, in terms of use, operations, and mitigation. Expected flood and wind conditions for different hurricane scenarios are compared with resistance to these hazards, providing insight to anticipated shelter performance.

The new shelter evaluation method was evaluated in a real case study for a large public hospital in the New Orleans area. The results of the case study were used to help the hospital develop its operational sheltering plans and evaluate mitigation alternatives. Some of the recommendations related to shelter operations were put into place during Hurricane Katrina.

CHAPTER 1: INTRODUCTION

1.1 Background

As a hurricane approaches, emergency officials begin issuing evacuation notices. While most people will comply with these warnings, there will always be those that cannot or will not evacuate. Hurricane evacuation shelters are opened throughout the community to provide those residents who do not leave a place to ride out the storm. Although the hurricane evacuation shelters are often managed by local chapters of the American Red Cross, it is primarily the community's responsibility to evaluate and select which facilities will be used as shelters. With the local emergency officials in charge of choosing shelters their options are normally limited to government facilities, with public schools being a top choice.

Over the years, cities near coastlines have become more populated and more people are choosing not to evacuate. In 1998 an estimated 50% of New Orleans (600,000 people) did not evacuate during Hurricane Georges (Howel, 1998). Although Georges narrowly missed New Orleans the need for more hurricane evacuation shelters became even more evident. On the other hand, finding an ideal evacuation shelter that can withstand a hurricane's wrath is difficult and emergency officials are normally left to compare and choose the best available, although not always the best suited.

1.2 Problem Statement

When designing a new facility for use as a hurricane shelter, FEMA 361 and Easley 2003 serve as good references and guidelines. However, there are not many guidelines for evaluating and retrofitting existing shelters. The State of Louisiana Hurricane Evacuation Selection Guidelines (LOEP, 2001) allows emergency management officials to evaluate and compare shelter facilities through a point system.

This helps officials choose the best facility for a shelter location. Although one facility may be better than another, it still may not be suitable for an intense hurricane. Ultimately, officials often do not know what specific intensity of storm their facilities can withstand and when not to use them. Critical infrastructure, such as hospitals and emergency management command centers, do not generally have the luxury to choose particular facilities or even areas inside their own facility for use as shelters. For instance, during tropical storm Allison (2001), Taub General Hospital had no choice but to stay open or otherwise there would have been no level one trauma centers during and after the storm in the Houston, Texas area.

The shelter site's topography, hurricane intensity, and approach direction can dramatically affect a shelters scenario. A facility that may be satisfactory for use as a shelter from a category two hurricane may receive ten feet of storm surge in a category three. An eastward moving storm may push five feet of storm surge into a particular shelter, but a westward moving storm may leave the same shelter dry. Beyond consideration of intensity and direction, a storm's forward speed can also alter the overall effects of the storm.

When evaluating a shelter facility it is easy to choose areas from a functional standpoint instead of life safety. The Turner Agri-Civic Center, in Desoto County Florida, had the ability to shelter over 1,000 people; however, in hurricane Charley (2004) a section of the roof pealed off and evacuees were forced to take shelter under stadium stands. Fortunately, only one person was injured, but if the roof had completely pealed off there would have been even greater risk of the building collapsing and possibly killing numerous people. In the end, emergency management officials must evaluate a shelter for functionality as well as structural integrity.

1.3 Goals and Objectives

The goal of this thesis is to develop a new methodology to evaluate buildings for use as hurricane shelters. The new methodology will help engineers determine the safest location to shelter evacuees and allow emergency officials to have a better grasp of their expected facility performance in order to make needed improvements for use as a hurricane shelter. This will be accomplished by creating a new method for evaluating existing shelters and applying the new method to a case study.

According to the new method, shelter needs will be determined by a review of the facility's building plans and an on-site inspection. Instead of using the more qualitative approach of the least-risk decision making process, the new method will be more quantitative in nature. Expected storm surge levels and maximum winds at the shelter site will be related to a hurricane's intensity and direction. The maximum wind values for the Saffir-Simpson categories will be adjusted for initial landfall and inland decay and then used with ASCE 7 and/or wind tunnel test results to determine the estimated wind pressures and loads on the building. Using the expected wind and flood conditions, analyses will be conducted on structural, cladding, and mechanical systems to develop failure scenarios related to a hurricane's direction and intensity.

The flood, wind, structural, cladding, and mechanical analyses will then be used to create the shelter plan, determining areas of high hazard and recommending the safest location to place evacuees during a storm. By relating expected performance to the hurricane's direction and intensity, the shelter plan will provide detailed information for emergency officials make necessary decisions for the specific approaching hurricane.

For buildings that are found not to be able perform to the desired hurricane intensity or capacity as desired, mitigation strategies and recommendations will be made.

CHAPTER 2: LITERATURE REVIEW

2.1 Hurricanes and Hurricane Wind Speeds

2.1.1 Overview

A hurricane is a type of cyclone that forms in the Atlantic Ocean, Caribbean Sea, Gulf of Mexico or Eastern Pacific Ocean. Starting as a tropical wave the low-pressure system normally develops near the equator. The low-pressure system draws air and begins to move in a counterclockwise motion in the Northern Hemisphere. Once the one-minute sustained wind speeds reach 39 mph it is then classified as a tropical storm and then a hurricane at speeds greater than 74 mph. Moving in its counterclockwise motion, the center of the storm will have the highest winds and decrease in speed further out. As the hurricane approaches land, its high winds can cause damage by pick up loose objects, creating wind-borne debris, push storm surge onto land, and blowing over large objects.

The current means of classifying a hurricane is with the Saffir-Simpson Scale. The Saffir-Simpson Scale categorizes hurricanes based on the storms central pressure, which is related to its maximum sustained wind speed. Table 2.1 is the Saffir-Simpson Hurricane scale with the associated wind speeds, barometric pressures. Also included in table 2.1 is the expected storm surge and potential damage related to each category. It is appropriate to relate storm surge with the hurricane intensity due to majority of the storm surge being caused by winds (NOAA, 2005a) as illustrated in figure 2.1.

2.1.2 Hurricane Wind Speeds

Understanding that wind speeds vary with height, a reference height of 33 ft above the ground is used as a standard reference for design and comparison purposes. Unlike the reference height, the reported measured time can differ depending on use. Naturally, the hurricane's winds will be comprised of short pockets of gust producing a peak winds. The longer the reported time the lower the average value, while a short reported time will have higher values. Addressing this issue, ASCE 7-95 (ASCE, 1996) published the Durst and Krayer-Marshall curves that allow the time to be adjusted, figure 2.2.

Table 2.1-Saffir-Simpson Hurricane Scale (NOAA, 2005b)

Saffir-Simpson Hurricane Category	Sustained Wind Speed (mph)	Storm Surge (ft)	Pressure (inches of Mercury)	Potential Damage
1	74-95	0-5	> 28.94	Minimal
2	96-110	0-8	28.50 - 28.91	Moderate
3	111-130	0-12	27.91 - 28.47	Extensive
4	131-155	0-18	27.17 - 27.88	Extreme
5	< 155	0-18+	< 27.16	Catastrophic

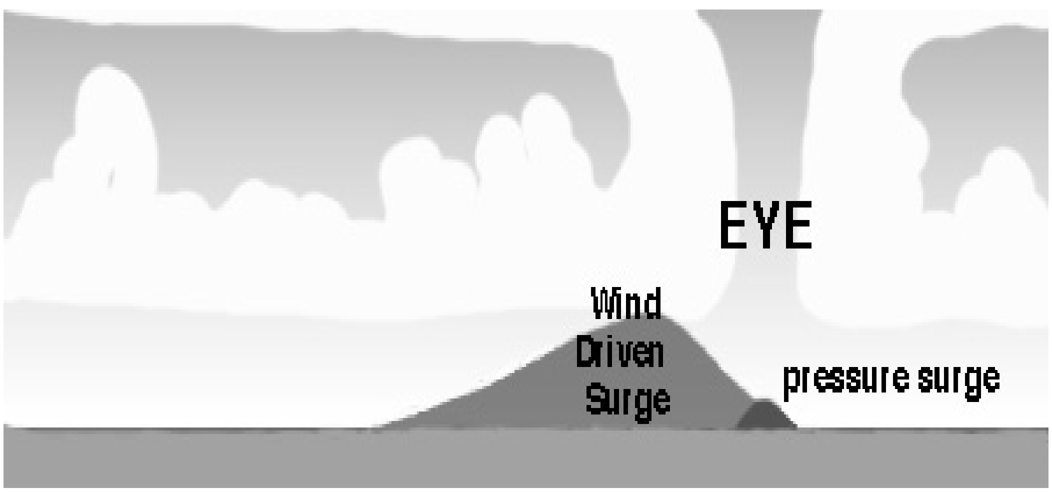

Figure 2.1-Hurricane Storm Surge Example (NOAA, 2005a)

When using the Saffir-Simpson scale it should be noted that wind speeds are reported in a 1-minute sustained wind speed, while ASCE 7-02 (ASCE, 2002) winds are reported in 3-second gust. Although ASCE 7 once used a sustained wind speed, it is imperative that wind speeds used for current editions be a 3-second gust due to assumption within that standard.

2.1.3 Decrease in Hurricane Wind Speed at Landfall

Once a hurricane makes landfall it will have an initial decrease in speed and continue to weaken as it moves further inland. Depending on the hurricanes strength and forward speed, the decay factor will vary. A fast moving category 5 storm will decay less than a slow moving category 3.

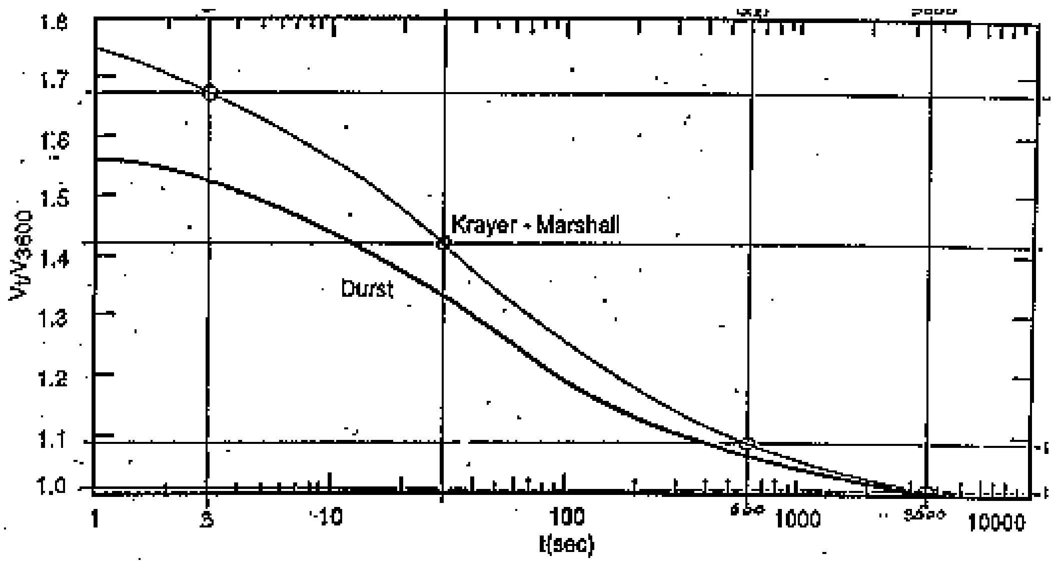

Figure 2.2-Krayer-Marshall curve (ASCE, 1996)

Easley (2003) discusses this event and recommended that research by Ho's, et al. (1987), table 2.3, decrease in inland wind speed used with Vickery's, et al. (2000), table 2.4, decrease in wind speed at the coastline be used due to the fact it best fit ASCE 7 (2002) wind speed map. Values shown in table 2.3 are various central pressure after landfall for the Gulf Coast Region. Although Ho did complete separate studies for the Florida peninsula and Atlantic Coast Regions, the values shown in table 2.3 are for the Gulf Cost regions.

2.2 Cladding Failure

Wind-borne debris can devastate a structure and should not be overlooked in hurricane design. Once a hurricane's wind speeds surpass an objects threshold of flight, the object will be picked up and pummel into surrounding objects. Eventually, unprotected cladding will break due to wind-borne debris, creating more wind-borne debris and propelling the problem.

Table 2.2-Peak Gust Wind Speeds for Saffir-Simpson Hurricane Categories (Vickery et al., 2000)

Saffir-Simpson Category	Max Sustained Wind Speed Over Water		Max 3-second Gust Speed Over Water		3-second Max Gust over Open Terrain at Landfall z_o=0.1 ft (.03m)	
	(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)
1	74-94	33.1-42.0	91-116	40.6-51.9	82-108	36.8-48.1
2	94-110	42.0-49.6	116-140	51.9-61.7	108-130	48.1-58.1
3	110-130	49.6-58.1	140-165	61.7-72.7	130-156	58.1-69.7
4	130-155	58.1-69.3	165-195	72.7-87.3	156-191	69.7-85.5
5	>155	>69.3	>195	>87.3	>191	>85.5

Table 2.3-Pressure Deficit vs. Time after Landfall, from Ho, et al. (1987)

Time After Landfall (hrs)	Pressure Deficits (Mb)								
0	40	60	80	85	90	95	100	105	110
2	34	51	68	72	76	78	80	81	82
4	30	44	59	63	66	67	68	69	70
6	26	40	53	56	58	59	60	61	62
8	22	34	45	48	50	51	52	53	54
10	20	30	40	42	44	45	46	47	47
12	18	27	36	38	39	40	41	41	42
14	16	24	32	34	35	36	36	36	36
16	14	21	28	30	31	32	32	32	32
18	12	19	25	26	27	28	28	28	28

Investigating the aftermath of a hurricane, it is obvious that debris from one destroyed structure becomes a weapon to compromise another structure. Common construction materials such as 2x4's, plywood, and roof gravel can easily become projectiles. In order to organize the objects found after a hurricane, debris was classified into three categories: (1) Lightweight – roof gravel, etc; (2) Medium weight – timber plank, etc; and (3) Heavyweight – utility poles, automobiles, etc (McDonald and Bailey, 1985). Organizing the debris into categories allowed for codes to test and rate hurricane construction materials, i.e. windows and doors, to withstand the appropriate debris.

2.2.1 Codes and Standards for Debris Impact Protection

Research over the years has allowed current standards to best represent expected debris and their impact characteristics. ASTM E 1886 (ASTM, 2002) ASTM E 1996 (ASTM, 2003a) and the Miami Dade Protocol are the current test standards for debris impact resistant material. Discussed in Easley (2003), Minor, et al. (1978) recommended when testing a buildings components and cladding, a medium weight debris, 12' long 2" x 4" wooden member, traveling at ½ of the design wind speed is recommended. Following Minor's suggestion and other supportive research (Wills, et al., 2001, and Lee and Wills, 2002) standards require either a 2" x 4" piece of lumber or gravel to be fired from a missile cannon at the test specimen. Figure 2.3 is an illustration of a 2x4 being fired from a missile cannon (FEMA, 2000)

2.2.1.1 ASTM E 1886 and ASTM E 1996

American Standards and Testing Materials (ASTM) E 1886 and 1996 address the topic of debris impact resistant testing. Firing the specified object at the test specimen and then being subjected to a cyclical pressure test, specimens that do not break and stay within specified tolerance can be accepted as an impact resistant product and assumed to withstand hurricane wind-borne debris.

When using these standards with ASCE 7 wind map, the correct wind zone is chosen, shown below, which is used to determine the necessary protection level and finally determine the missile size and impact speed, tables 2.4 and 2.5. After the impact testing, the specimen is subjected to a cyclical pressure test shown in table 2.6.

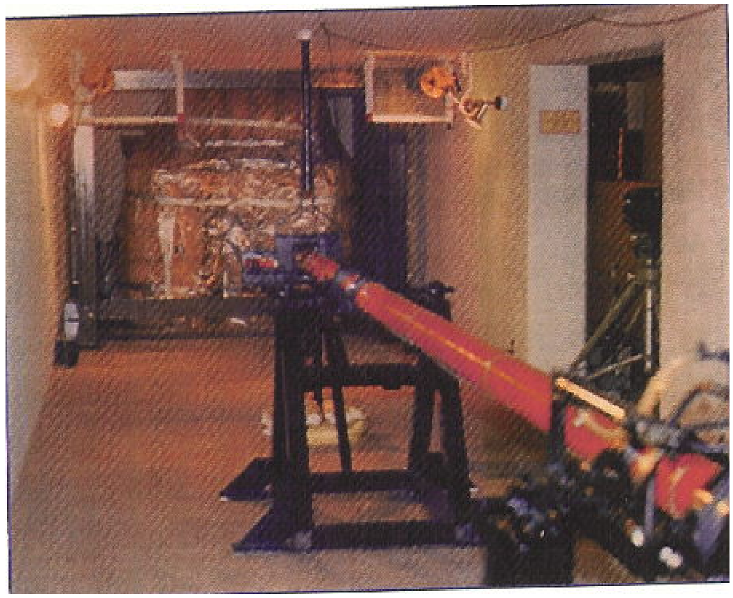

Figure 2.3-Missile Cannon (FEMA, 2000)

Table 2.4-Level of Protection (ASTM, 2002)

Level of Protection	Enhanced Protection (Essential Facilities)		Basic Protection		Unprotected	
Assembly Height	< (30 ft) 9.1 m	> (30 ft) 9.1 m	< (30 ft) 9.1 m	> (30 ft) 9.1 m	< (30 ft) 9.1 m	> (30 ft) 9.1 m
Wind Zone 1	D	D	C	A	None	None
Wind Zone 2	D	D	C	A	None	None
Wind Zone 3	E	D	D	A	None	None
Wind Zone 4	E	D	D	A	None	None

Table 2.5-Missile Level (ASTM, 2002)

Missile Level	Missile	Impact Speed (m/s)
A	2 g +/- 5% steel ball	39.62 (130 ft/s)
B	910 g +/- 100 g (2.0 lb. +/- 0.25 lb) 2x4 in 52.5 cm +/- 100 mm (1ft - 9in +/- 4 in) lumber	15.25 (50 ft/s)
C	2050 g +/- 100 g (4.5 lb +/- 0.25 lb) 2x4 in 1.2 m +/- 100 mm (4ft +/- 4 in) lumber	12.19 (40 ft/s)
D	4100 g +/- 100 g (9.0 lb +/- 0.25) 2x4 in 2.4 m +/- 100 mm (8 ft +/- 4 in) lumber	15.25 (50 ft/s)
E	4100 g +/- 100 g (9.0 lb +/- 0.25) 2x4 in 2.4 m +/- 100 mm (8 ft +/- 4 in) lumber	24.38 (80 ft/s)

Wind Zone1- 110 mph (49 m/s) < basic wind speed < 120 mph (54 m/s), and Hawaii

Wind Zone 2- 120 mph (54 m/s) < basic wind speed < 130 mph (58 m/s) at greater than 1.6 km (one mile) from the coastline. The coastline shall be measured from the mean high water mark.

Wind Zone 3- 130 mph (58 m/s) < basic wind speed < 140 mph (63 m/s), or 120 mph (54 m/s) < basic wind speed <140 mph (63 m/s) and within 1.6 km (one mile) of the coastline. The coastline shall be measured from the mean high water mark.

Wind Zone 4- basic wind speed >140 mph (63 m/s).

Table 2.6-Air Pressure Cycling (ASTM, 2002)

Loading Sequence	Loading Direction	Air Pressure Cycles	Number of Air Pressure Cycles
1	Positive	0.2 - 0.5 P_{pos}	3500
2	Positive	0.0 - 0.6 P_{pos}	300
3	Positive	0.5 - 0.8 P_{pos}	600
4	Positive	0.3 - 1.0 P_{pos}	100
5	Negative	0.3 - 1.0 P_{neg}	50
6	Negative	0.5 - 0.8 P_{neg}	1050
7	Negative	0.0 - 0.6 P_{neg}	50
8	Negative	0.2 - 0.5 P_{neg}	3350

2.2.1.2 Miami-Dade Protocol

After Hurricane Andrew devastated Florida created their own set of standards for hurricane resistant products (FLBC, 2004), with the Miami-Dade county adopting their own stringent guidelines on impact criteria. Following ASTM standards, Miami-Dade required products to go through a wind driven rain penetration, uniform static air pressure, large missile impact, and cyclic wind pressure test. The wind driven rain penetration test applies a jet of water at wind velocities of up to 110 mph for five minutes, requiring the system to not leak more than 0.72 oz over a 15 minute period.

Completing the rain penetration test, a static pressure is applied in increments of 30 seconds until the maximum static pressure of 1.5 times the design pressure is achieved. Next, the specimen must resist impact from three type D missiles with the 2" x 4" piece of lumber not penetrating or creating any significant openings to pass the test. Finally, a cyclical pressure test is conducted in increments until a load of 1.3 times the design pressure is achieved.

2.2.1.3 Easley

ASTM 1996 (ASTM, 2003a) and ASCE 7 (ASCE, 2002) allow certain facilities to withstand a smaller missile, 2 g steel ball projected at 130 ft/s. With the intentions of hurricane shelters to protect lives and not property, hurricane shelters are require to withstand the 9 lb 2" x 4" piece of lumber. Documented in Easley (2003) it is suggested that instead of using a set velocity allow the velocity to change based on hurricane classification. The following are the recommendations made in Easley (2003):

- Any building envelope components must be able to withstand impact from a 12 ft long 2’’ x 4’’ wooden missile traveling at ½ the 1-minute averaging time wind

- The requirement for the component to be deemed to have passed the impact test depends on the use classification of the building. For example, the requirement for the building classified as a Function Critical facility is far more stringent than that of a building classified as a refuge.

- There are no small missile impact requirements suggested. As long as the building envelope components are deemed to pass the above requirements, it is assumed that it will be able to resist any type of small impact.

2.2.2 Window Deflection due to Uniform Pressure

2.2.2.1 ASTM E 1300

ASTM E 1300 (ASTM, 2003b) is the current design standard for determining the deflection and failure rate of glass due to a uniform load. As hurricane wind pressures increase glass will begin to deflect and eventually come out of its frame or break. Determining the exact behavior of every window is difficult, inaccurate and time consuming due to its nonlinear properties. On top of the properties being nonlinear, glass plates will not always behave identical and deteriorate over time. Addressing this concern, ASTM E 1300 uses a probability of failure and the surface flaw parameters, m and k used, fit a Weibull probability distribution (Beason, et. al., 1985).

According to Minor (Minor, 2004) windows will loose 15%-20% of their strength in the first 20 years and 5%-10% in the following 20 years. To account for the ageing of the window ASTM E 1300 uses a k value equal to 2.86 x 10^{-53} N^{-7} m^{12} (1.365 x 10^{-29} in lb^{-7}) and a m of 7, which relates to a window 20 years in service. Figure 2.4 is a chart from ASTM E 1300 to determine the design pressure for an annealed glass based on a eight per thousand failure rate and supported on four sides.

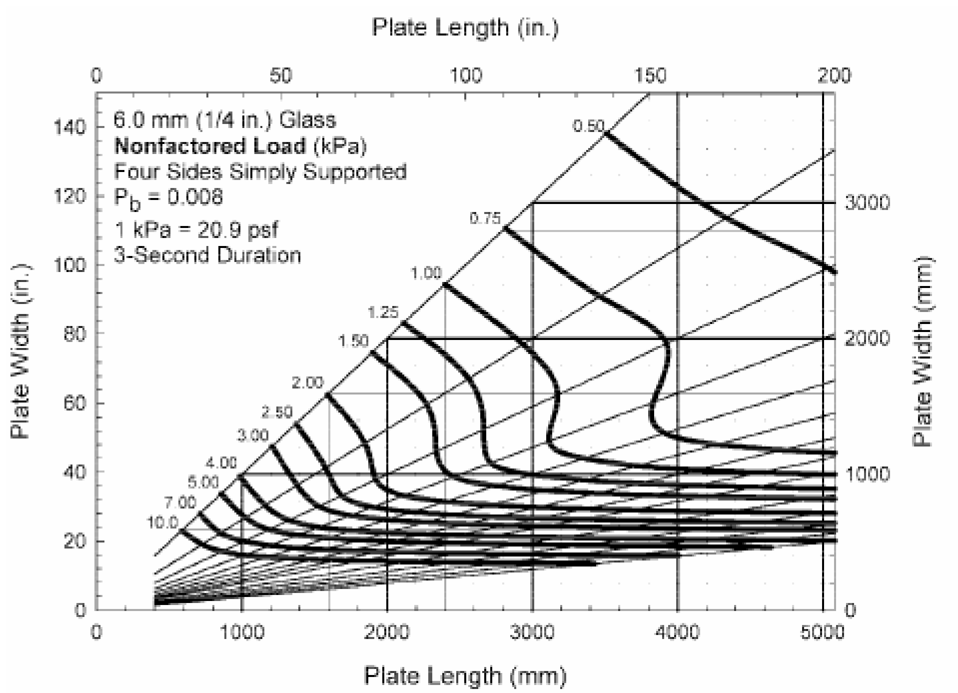

Figure 2.4-ASTM E 1300 Design Pressure Chart for ¼’’ Glass Supported on Four Sides

Using figure 2.4 for a ¼’’ lite of annealed glass supported on four sides, a vertical line is drawn for length and horizontal for the width. Interpolation is then preformed at the intersection of both lines and the non-factored load (NFL) is determined. To determine the load resistance for the glass the NFL is multiplied by the glass type factor

(GFT) in table 2.7, which is based on if the lite is annealed (AN), heat strengthened (HS), or fully tempered (FT). It should be noted that for hurricane winds the short duration load should be used.

Table 2.7-Glass type factor (ASTM, 2003b)

Glass Type Factor (GTF) for a Single Lite of Monolithic or Laminated Glass		
Glass Type	Short Duration Load	Long Duration Load
AN	1.0	0.5
HS	2.0	1.3
FT	4.0	3.0

Requiring the probability of failure for a window to be zero would be costly for most design. Therefore, ASTM E 1300 allows designers to choose a probability of failure from zero to 50 per thousand with a recommendation of 8 per thousand for normal use. Equation 2.1 from ASTM E 1300 can be used to vary the probability of failure, however, it can only be used for a maximum failure rate of 50 per thousand. If a failure rate of greater than 50 per thousand is desired experimental and numerical modeling must be completed due to the variability and nonlinear functions of a the lite. The following is an example using equation 2.1 for a 60" x 61" x 7/32" annealed glass with a design pressure of 50 psf (ASTM, 2003b):

$$P_b = k(ab)^{1-m}\left(Et^2\right)^m e^J \qquad [2.1]$$

Where:

P_b	= the probability of breakage
k and m	= surface flaw parameters (values assumed in ASTM E 1300)
a	= plate length (long dimension), in
b	= plate width (short dimension), in
E	= the modulus of elasticity of glass, psi
e	= 2.7182
J	= the stress distribution factor, based on applied load and aspect ratio
q	= applied load, psi

t = true glass thickness, in
A = area of the rectangular glass plate, in^2

Assumptions:

- P_b must be less than 0.05 or 50 lites per thousand
- $k = 1.365 \times 10^{-29}$ in lb^{-7}
- m = 7
- $E = 10.4 \times 10^6$ psi
- $q_1 = 50$ psf
- J = 20.9

$$P_b = 1.365^{-29}\left[(60)(61)\right]^{(1-7)}\left[(10.4^6)\left(\tfrac{7}{32}\right)^2\right]^7 e^{20.9} = .051$$

2.3 Flood Analysis

The National Oceanic and Atmospheric Administration developed a storm surge model called SLOSH, short for Sea, Lake, Overland Surge from Hurricanes (NWS, 2001) which allows a user to determine the expected storm surge levels at a specific site. Different approach directions, hurricane categories, forward speed, and tide levels can be used to determine the worst case and expected scenarios. SLOSH is primarily use is for emergency management community for hurricane evaluation planning and operations. The SLOSH display program provides estimates of surge flooding elevations based on NGVD and does not include wave heights. SLOSH has an estimated accuracy of plus or minus 20 %.

When using SLOSH, there are three settings; a MEOW (maximum envelope of water) represents a maximum the height of storm surge for a locations based on a "family" of parallel hurricane tracks for the specified direction. This option allows the user to choose different storms categories and directions. The MOM (maximum of maximums) is the worst-case scenario for the chosen basin for each Saffir-Simpson category. The final setting is a database of historic storms and their flood levels due to storm surges.

2.4 Guidance for Hurricane Shelters

Considered the main design code for wind loads on structures, ASCE 7 (ASCE, 2002) mainly addresses hurricane shelters through the importance factor. When importance factors are increased, the mean reoccurrence interval (MRI) of the design increases. Table 1-1 in ASCE 7-02 indicates that shelters, certain hospitals, and essential facilities are listed as a category IV. Table 6-1 in ASCE 7-02 provides that the importance factor for category IV structures is 1.15. In hurricane prone regions, this corresponds to a mean recurrence interval equivalent to an 100 year storm.

2.4.1 FEMA 361

Federal Emergency Management Administration (FEMA) 361 "Design and Construction Guidance for Community Shelters" (FEMA, 2000), focuses on shelters equal to or greater than 1000ft^3. FEMA 361 main purpose is to function as a guideline to building new hurricane/tornado shelters that will be able to provide an "near-absolute protection" from an high wind event. In order to provide the desired near-absolute protection, FEMA developed a design wind map that is based on the maximum expected wind speeds for a region, figure 2.5. Reviewing figure 2.5, majority of the hurricane prone regions are in Zone 3 having a design wind speed of 200 mph, which relates to a strong category 5 hurricane on the Saffir-Simpson scale.

2.4.2 Easley

Easley (2003) developed a performance-based shelter design criteria where design wind speeds are selected based on the Saffir-Simpson scale. Using the suggested method allows emergency officials to design shelters based on their shelter demands, available budget, and any other relevant considerations (Easley, 2003). With the performance-based design, emergency officials have a better understanding of how their shelters will perform with an approaching hurricane.

In order to accomplish the desired design criteria and use ASCE 7 (ASCE, 2002), to determine design loads, Easley investigated and adjusted factors to substitute the probabilistic approach to the desired performance-based. Doing so, the importance factor, directionality factor and determination of wind speeds were modified.

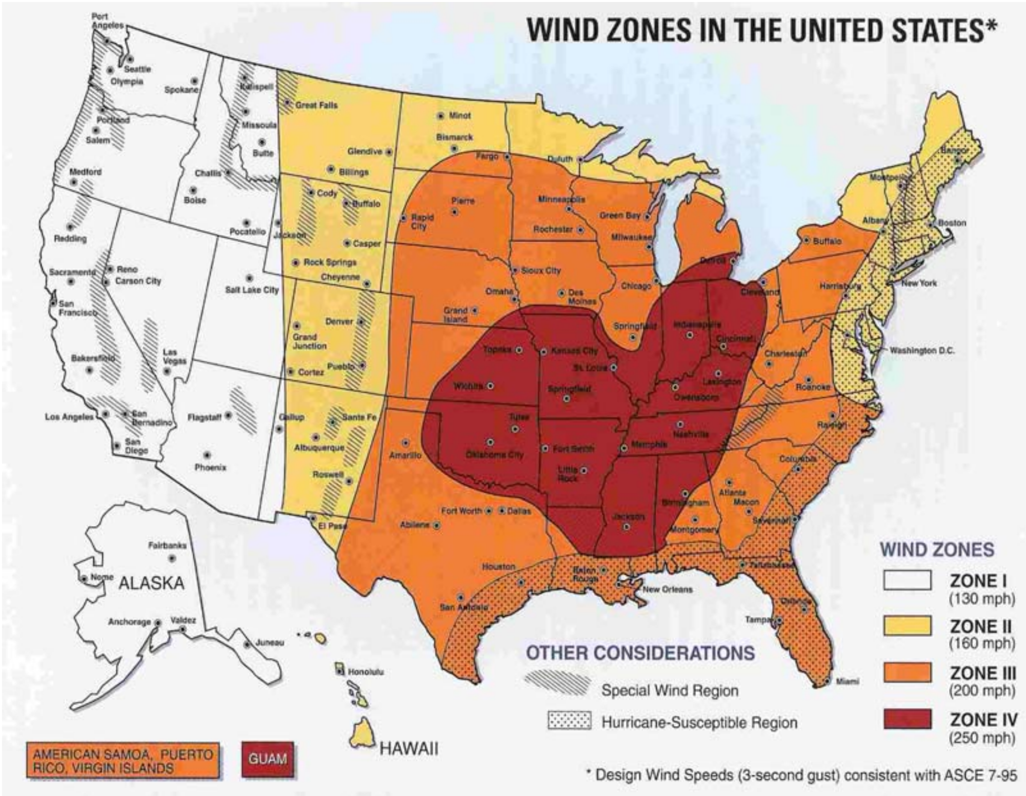

Figure 2.5-Design Wind Speed Map for Community Shelters (FEMA, 2000)

When a community plans on building an hurricane shelter, it first classifies the facility into one of the five essential facility classification; Function critical, base of operations for response, hurricane shelter, refuge of last resort, emergency equipment/ supplies storage facility. Next, the allowed level of damage to the building is determined; Overall danger to life safety, primary structural damage, building envelope damage: windows/ doors, building envelope damage: roof and wall systems, mechanical and plumbing systems damage: electrical/ lighting systems, mechanical and plumbing systems damage: HVAC equipment, mechanical and plumbing systems damage, plumbing systems.   Finally, the expected wind speeds at the site, debris criteria, storm surge flooding are determined and correlated with the Saffir-Simpson scale and desired performance level.

2.5 Hurricane Shelter Evaluation

2.5.1 Louisiana Office of Emergency Preparedness Guidelines

"Hurricane Evacuation Shelter Selection Guidelines" (LOEP, 1997) serves as the primary guideline for hurricane shelter assessment in Louisiana. It was developed so emergency management officials could complete comprehensive shelter assessments and provide individuals with an understanding of what makes a safe hurricane shelter. Using a least-risk decision making process, shelters construction method, wind effects, storm surge, rainfall flooding and hazardous material considerations are evaluated and compared amongst other shelters in the community. This allows a community to select the least vulnerable shelter (LOEP, 1997).

2.5.2 ARC 4496

American Red Cross (ARC) 4496 "Guideline for Hurricane Evacuation Shelter Selection" (ARC, 2002) is a four page guideline to evaluating and selecting hurricane shelters. Similar to the LOEP guidelines, ARC 4496 uses a least-risk decision making process. Being four pages long, this guideline provides general suggestions. Flood modeling from storm surge and inland flooding is required to verify the shelter is located outside a Category 4 storm surge. Structural integrity due to high winds should be checked and rated and have a minimum capability to withstand the wind loads according to ASCE 7-88.

2.5.3 FEMA 361

FEMA 361, states that using its method to retrofit an existing shelter can cost 10-15% more than constructing a new shelter (FEMA, 2000). Although this manual does discuss evaluating existing hurricane shelters, it briefly address flood hazards and only provides minimal recommendations. Located in appendix B in FEMA 361 are the forms for an on-site assessment. The format is based on a point system with five sections; general building information, selecting the refuge area, wind, flood, and seismic hazard checklist.

2.6 Wind Design

2.6.1 General Procedure

ASCE 7-02 (ASCE, 2002) allows engineers to choose between three methods for determining wind loads on a structure; the simplified method, analytical method, and wind tunnel analysis. The analytical method, method 2, most commonly used, is based on previous full scale and wind tunnel studies. When determining the design pressures, factors such as the exposure, topography, directionality, velocity, importance, gust duration, internal pressure, and design height are accounted for. Equations 2.2 and 2.3 are the ASCE 7 equations used to determine the design pressures in the analytical and wind tunnel analysis methods. Majority of the factors shown in equations 2.2 and 2.3 are based on site conditions and remain constant, allowing the main variable to be height.

$$p = qGCp - q_i GCp_i \qquad \text{[2.2] (ASCE, 2002)}$$

$$q_z = .00256 K_z K_{zt} K_d V^2 I \qquad \text{[2.3] (ASCE, 2002)}$$

p = design pressure (lb/ft^2)
q = velocity pressure (lb/ft^2)
G = gust effect factor
Cp = external pressure coefficient
q_i = velocity pressure for internal pressure
GCp_i = product of internal pressure coefficient and gust effect factor
q_z = velocity pressure evaluate at height z above ground (lb/ft^2)
K_z = velocity pressure exposure coefficient evaluated at height z
K_{zt} = topographic factor
K_d = wind directionality factor
V = basic wind speed (mph)
I = Importance factor

An advantage to using the analytical method is the ability for engineers to use it for design of most low and high-rise structures. With that being said, the analytical method is included in majority of structural software programs. For structures that have a unique geometry or small variation in loads can equate to significant cost savings, method three, wind tunnel analysis, allows for a more detailed analysis; possible providing lower design pressures than those obtained with the analytical method. Wind tunnel testing takes a dimensional model of the proposed structure and tests it in a scaled wind tunnel, determining the correct pressures due to exposure classification and direct surroundings. This method produces the closest results to that which the full-scale building receives.

2.6.2 Exposures Categories

To address different surface roughness and surface irregularities, ASCE 7 developed three exposure categories; B, C and D. Exposure B is for urban and suburban terrain with numerous closely spaced obstructions, C open terrain with scattered obstructions less than 30ft and D is for open water not in hurricane prone regions. When using method 2, the exposure category that best fits the site conditions of the structure to be built or evaluated is chosen and used in conjunction with the velocity pressure exposure coefficient.

2.6.3 Main Wind Force Resisting System

ASCE 7 analyzes the structure as two different components, main wind force resisting system (MWFRS) and components and cladding (C&C). The MWFRS is the structural framing that supports the buildings. Although this part of the building is not generally exposed to the wind directly, it will carry all the wind force. To determine the design pressures for the MWFRS, equations 2.2 and 2.3 are used in conjunction with the corresponding numerical values for the desired structure found in ASCE 7-02.

2.6.4 Components and Cladding

Components and cladding are elements of the building envelope that do not qualify as a part of the MWFRS (e.g. windows and walls). They are subject to natures force and must be protected against high winds, flying debris, rain and flooding. Just like the MWFRS, ASCE 7-02 has figures and tables with the corresponding values for design of components and cladding. The main noticeable difference in using equation 2.2 for components and cladding vs. MWFRS is the combination of the gust factor and pressure coefficient, GC_p. Besides the combination and change in values for GC_p, the remaining values do not vary from the values obtained for the MWFRS.

2.6.5 Internal Pressure Coefficient during Hurricane Conditions

The internal pressure coefficient, GCp_i, can dramatically affect the design when ASCE 7 is used to determine pressures on a shelter. Changing the internal pressure from an enclosed to a partially enclosed building can potentially increase the design pressures up to 50%. ASCE 7 classifies internal pressure into three groups: open, partially enclosed, and enclosed. For larger shelters, volume over 1,000ft^3, the internal pressure coefficient should be treated as partially enclosed (NSSA, 2001). ASCE 7 does not allow for hurricane shelters to be built without impact resistant glass, therefore it recommends an enclosed classification for design. However, FEMA 361 (FEMA, 2000), FEMA 320 (FEMA, 1999), Kilcollins (2004), and Easley (2003) all agree and recommend that evaluation and design of hurricane shelters should be designed for partially enclosed.

2.7 Method III, Wind Tunnel Testing

ASCE 7 method three allows for wind tunnel testing to be used to determine pressure coefficients on a desired structure. In order to achieve the proper pressure coefficients, certain procedure and guidelines must be followed. ASCE Manual No. 67 (ASCE, 1999) is the current manual for conducting wind tunnel tests on buildings and structures. This manual offers the proper procedures on modeling scaled flow conditions and a guideline on how to achieve proper pressure coefficients.

Following ASCE Manual No. 67, the wind tunnel and test specimens must meet the following requirements for low and high-rise experiments:

- Vertical distribution of the mean wind speed and the intensity of the longitudinal turbulence components shall be modeled
- Important properties of atmospheric turbulence, in particular the relevant length scale of the longitudinal turbulence components shall be modeled to approximately the same scale as that sued to model the building or structure
- The longitudinal pressure gradient in the wind tunnel test section should be sufficiently small as not to significantly affect the results
- Have a blockage ratio (ratio of frontal area of the model) less than 10%, unless validation is conducted through additional tests at a smaller scale
- Instrumentation calibrated and free of significant acoustic effects, electrical noise, mechanical vibration, and spurious pressure fluctuations, including fluctuations of the ambient pressure within the wind tunnel caused by the operation of the fan, door opening sand the influence of atmospheric wind

It is also recommended that for urban settings, scaled reproduction of all major buildings and structures within 300 to 800 meters from the site be included in the testing, covering the entire turntable of the wind tunnel.

It should also be noted when using wind tunnel tests that ASCE 7 requires pressure coefficients not be less than 80% of results from method two. To prevent surrounding buildings that may one day be removed that provide shelter in wind tunnel tests, the lower limit was established.

2.8 Pressure Measurement

As the wind pressures react with a wind tunnel model they are recorded with a pressure transducer. With transducers getting smaller, on larger models the transducer can be placed directly on the inside surface of the model reducing the distance the pressure has to travel before being recorded. Models that have numerous pressure taps or are smaller in size will not be able to have a transducer inside the model and must be externally mounted. To transmit the pressure readings, plastic tubing is used to connect the pressure taps to the transducer.

When measuring pressures with plastic tubing there are three commonly used methods; short, restricted and leaked. Tubing that is between 20 -100 mm long is referred to as “short” tube systems (Homes, 2001). Being short, the resonant frequency will naturally be high resulting in a low dissipation of energy and a high amplitude response at the peak values (Homes, 2001). When this method is used, the resonant frequencies are higher than the recorded frequencies and do not affect the pressure results.

Tubing between 150- 500 mm frequencies can interfere with the peak pressures and the restricted method can be used as a filter. Changing the diameter of the tubing by reducing the tubing will reduce the resonant peaks and give a linear phase response at frequencies up to 200 Hz (Homes, 2001).

For longer tubing, 1 meter, and frequencies of 500 Hz a controlled leak close to the transducer can provide a relatively flat amplitude frequency response. Unlike the other methods, this method is not used as much as the other systems for low-rise structures due to the fact transducers continually are reducing in size, allowing them to be placed closer to the pressure tap.

2.9 Long Term Properties of Concrete

Due to concrete requiring a hydration to activate, when exposed to an outside environment its long-term properties will change. Over time the water to cement ratio will decrease, increasing the compressive strength, flexural strength, and modulus of elasticity. Concrete that has been exposed to a humid environment can expect to have an increase in compressive strength from 30 to 40 percent over a 20-year period compared to the 28-day strengths. However, concrete that has been in a dry environment, such as an air-conditioned room, will only see minimal change in the long-term properties (Woods, 1991).

CHAPTER 3: METHODOLOGY

3.1 Introduction

As a hurricane approaches, community leaders and emergency management officials need a list of predetermined, suitable hurricane shelter facilities in hand. While some suitable hurricane shelter facilities are an obvious choice, other times it may not be as clear. Shelter facilities constructed in accordance with FEMA 361, or NSSA 2001 should always be used over facilities that are not designed with supplemental use as a hurricane shelter in mind. However, most public, community buildings are not specifically designed to function as a hurricane shelters. Evaluating these facilities can be difficult and the result may still not provide a substantial impression on what type or degree of storm the structure can withstand.

One procedure used for evaluation of a facility to be used as a hurricane shelter is the least-risk decision making process. The Louisiana Office of Emergency Preparedness Hurricane Evacuation Shelter Selection Guidelines (LOEP) uses the least-risk method to determine the safest shelter for a community, which is based on an interpretation of ARC 4496 (ARC, 2002) shelter standards. This process incorporates the evaluation of wind, flooding due to rainfall and storm surge, and locating hazardous sites. Each category is then placed into one of three classifications, preferred, acceptable, or marginal. Once a risk level has been determined for each proposed facility, the facilities are ranked least to highest risk and the community will use the least risk facilities first and so on until the community’s sheltering needs are met. Although a shelter might have a lower risk level compared to other shelters, this still may not be satisfactory for certain hurricanes. Using LOEP guidelines does not give emergency officials an understanding on what intensity hurricane their shelters can withstand, rather an idea on which shelters are better than others.

Evaluating a shelter solely based on design criteria can be confusing. Building codes and standards are based on probabilistic odds or a mean recurrence interval (MRI) that a certain event will happen within a given period of time. As the MRI for a given building increases, the overall performance against a storm also increases. For shelter evaluation, it is impractical to directly compare or adjust a storm's MRI to follow the Saffir-Simpson hurricane scale. In the end, emergency managers are not concerned with the statistical odds their shelter was designed for or can withstand but will it provide the needed protection for the approaching hurricane.

Instead of dealing with the statistical mess, FEMA 361 uses a method of "near-absolute protection" which increases the design wind speeds to an extreme event situation. However, statistically when wind speeds are increased to extreme event levels the MRI also increases to a 2,000 – 10,000 year storm (Easley, 2003). Evaluating a shelter that uses this method for design is cut and dry. If the shelter is designed to withstand the fastest winds possible for that area, then it should be capable of protecting evacuees from a hurricane wind. Using the "near-absolute protection" approach would be ideal but not financially practical for most communities. Consequently, this method is not a widely used method for hurricane shelters.

Easley (2003) developed a performance-based design approach. Instead of designing a shelter based on statistical odds or forcing a community to build a shelter they might not be able afford or need, his method is directly correlated to the communities needs. By structuring his method with the Saffir-Simpson scale and the expected hurricane conditions at each shelters site, community officials can determine what strength of hurricane they need their shelters to withstand.

This thesis proposes a new method for evaluating existing facilities for use as hurricane shelters. Like Easley, analysis will be based on hurricane intensities at landfall instead of probabilistically determined wind speeds and flood elevations. Based on wind, structural, cladding, mechanical, and flood analysis, the proposed method will provide a detailed report giving emergency management officials charts of each shelter allowing them to place evacuees in the safest areas, as well as know each shelters capabilities against hurricanes of different intensities and tracks. With a better understanding of a shelter facility's capability, emergency officials will know when to issue a mandatory evacuation and what needs to be done in order to prepare a shelter for a particular hurricane scenario.

Besides evaluating existing conditions for a facility's use as a hurricane shelter, mitigation strategies should be reviewed. The mitigation strategies will be based on a detailed understanding of the shelters weakness allowing for the need improvements.

3.2 Procedure for Hurricane Shelter Assessment and Mitigation Planning

The following is a brief overview of the proposed procedure:

1) Shelter needs requirements
    - Investigate needs of client
    - Meet with facility operators and emergency management officials responsible for shelter operations at the facility

2) Building plans and specifications review
    - Gather and review structural, architectural, and mechanical plans
    - Obtain an understanding on type of facility and construction methods

3) Building inspection
    - On site inspection of shelter and surrounding terrain
    - Evaluate shelter areas based on potential hazards
    - Locate areas suitable for sheltering

4) Flooding vulnerability analysis
    - Determine expected flood levels at shelter site
    - Use flood levels to determine the flood hazard

5) Wind analysis
    - Determine overall wind forces acting on main structural frame
    - Determine localized wind pressures for analysis/design of windows, shutters, and other cladding systems

6) Structural systems analysis
    - Determine original wind design criteria
    - Determine maximum wind speed that can be resisted by the Main Wind Force Resisting System (the main structural frame of the building), using computer analysis and data from wind engineering literature and results of wind tunnel testing

7) Cladding systems analysis
    - Determine original wind design criteria
    - Determine maximum wind speed that can be resisted by the components and cladding (windows, walls, shutters, etc) using computer analysis and data from wind engineering literature and results of wind tunnel testing
    - Determine capabilities due to wind-borne debris
    - Estimate vulnerability to water from roof leaks or wind driven rain

8) Mechanical systems analysis
    - Determine elevations of critical components of building mechanical and electrical systems
    - Estimate effects of wind and flood on mechanical systems operations

9) Shelter plan
    - Using results from steps 4-8, classify shelter areas based on risk
    - Determine optimal and suitable shelter areas

10) Mitigation plan
    - Using the shelter plan, summarize areas of high risk and potential hazards
    - If applicable, make recommendations for improvement

3.3 Determine Shelter Needs

Not all shelters can withstand a category 5 hurricane and not all communities need every shelter to withstand one. Before any planning or evaluation can be done the needs of the client must be determined. Determining those needs will provide a gage on the depth of the evaluation and develop a good client relationship. If mitigation strategies plan on being addressed, an understanding on what the client can afford or receive through grants is fundamental.

A meeting with the shelters owner or superintended and emergency management should be set up. In this meeting, an overview of previous shelter evaluations should be presented, giving the client an understanding of what to expect and what they might want. Establishing what their sheltering needs are fundamental and must be determined prior to analysis.

3.4 Review Building Plans

Although not always available, an as-built set of plans or design drawings of the building's structural, architectural and mechanical plans should be obtained for the shelter to be evaluated. In large complex facilities, it is important that an as-built set of plans be used instead of preliminary plans. Frequently, plans are made years prior to a building being built and often have minor changes. Smaller facilities normally do not encounter this problem and commonly have only one set of plans. Using the plans, determining the locations and sizes of the structural members, architectural details, and electrical junction box and generators will be necessary for the structural, cladding and mechanical analysis completed later. Having an understanding of how the shelter was built will allow for an efficient walk through and a predisposed awareness on suitable shelter locations.

From the plans and specifications the design wind speed and year the building was designed and built can often be determined. If the design wind speeds are not included on the plans, determine the completion date and use that year's code. Review the structural plans and obtain an understanding of the type of structure and areas that might not be satisfactory for a hurricane shelter. Table 3.1 is a guide on how different structural systems will perform compared to each other. This table is intended to be used as a guide and a detailed structural analysis, discussed later, should be completed.

Table 3.1 – Structural Systems Performance (LOEP, 1997)

Building Construction Type Ranking Table * Heavy Concrete frame means a monolithically poured reinforced concrete frame capable of resisting overturning moments	
Relative Strength	**Main Wind Force Resisting System (MWFRS)**
Strongest	High-rise heavy concrete of steel frame
	multistory braced heavy steel frame
	multistory heavy concrete* or steel frame with fully reinforced shear walls
	multistory heavy concrete* of steel frame with partially reinforced shear walls
	multistory fully reinforced masonry wall bearing
	single-story heavy concrete* frame with fully reinforced shear walls
	single-story fully reinforced masonry wall bearing
	single-story tilt-up or precast concrete wall bearing panels
	multistory partially reinforced masonry wall bearing
	multistory unreinforced masonry wall bearing
	single-story heavy concrete* frame with partially reinforced shear wall
	single-story pined steel frame with partially reinforced masonry shear walls
	single-story partially reinforced masonry wall bearing
	single-story unreinforced masonry wall bearing with pilaster-bond beam
	light-wood or metal stud wall framing with plywood sheathing (SSTD 10-93)
	preengineered Metal Building with light-gauge metal cladding (MBMA 1986 or more recent)
	light wood or metal stud wall framing with non-plywood sheathing (SSTD 10-93)
	pinned steel frame with light stud or unreinforced masonry shear walls (Noncompliant)
	pinned/ precast concrete frame with light stud or unreinforced masonry shear walls (Noncompliant)
Weakest	Unreinforced masonry wall bearing (Noncompliant)

Obtaining architectural plans will indicate material used for exterior walls and window dimensions and thickness. Mechanical plans will show where the control panels are and if there are any back-up generators. This will become important when flooding due to storm surge is addressed.

3.5 Onsite Inspection

Although the plans may show areas that might potentially provide adequate shelter, over the years, updates may have occurred, compromising or improving a shelter area. An onsite visit will provide an overview of the condition of the shelter, surrounding terrain and any potential threats.

When evaluating an existing hurricane shelter, highlighting and making notes on a printed floor plan will save time and confusion. Figure 3.1 is an example of an inspected hurricane shelter. Green was used for interior areas with no windows, blue for window locations, and red for areas that were not to be used shelter evacuees during the storm. These certain colors do not have to be used, but it is suggested to color coordinate similar areas. Besides color-coding, any obvious threats to the shelter should be determined and noted.

Accessing the roof will provide an overview of the surrounding terrain and any potential threatening objects during a hurricane, such as neighboring roof gravel or large trees. It is important to determine any lay down hazards or loose debris and indicate where it is relative to the shelter.

If the plans could not be obtained, the structure systems, cladding materials and mechanical information should be determined while on site. The type of roof, (e.g. light angle, concrete, etc.), must be determined and any areas with large spans should be noted. The overall building integrity should be evaluated and any cracks in the concrete and significant water damage due to leaks documented. When evaluating the existing windows and frames, commonly heat strengthened, heat tempered, or impact resistant glazing is marked near the bottom corner. If no mark can be found, it should be assumed the glass is annealed. Glass thickness can be determined with a glass thickness sensor.

For remote sites, a hand-held GPS can be used to determine the latitude and longitudinal coordinates, however, with an physical address most coordinates can be found online.

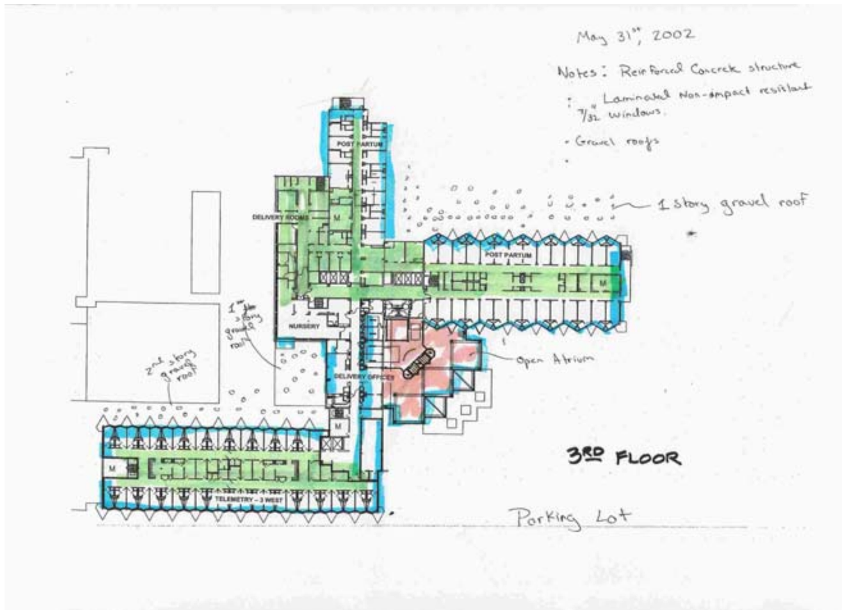

Figure 3.1-Example of on Site Evaluation

3.6 Flood Analysis

3.6.1 Storm Surge

As a hurricane approaches land, high winds and the storms low pressure push water from the ocean onto the land. The stronger the hurricane and its winds are, the higher the storm surge. For low lying or areas near the coast the storm surge can completely cover buildings. Table 3.2 shows typical storm surge values at the coast based on hurricane's intensity. Surge elevations inland are highly dependant on local topography and distance from the coast.

The SLOSH (NWS, 2001) software modeling package can be used to determine the amount of storm surge a particular location will receive based on a hurricane's intensity, track, forward speed, and the tide. Flood levels in SLOSH are provided in National Geodetic Vertical Datum (NVGD) and should be adjusted to the shelter's ground elevation. For low-lying areas that are protected by major floodwalls and or levees, SLOSH assumes the floodwalls will hold throughout the storm. When evaluating a hurricane shelter for storm surge, mean and high tides should both be considered. Each storm track as well as category should be run with the flood depth at the site and distance from the coast documented. This will provide a table of expected flood levels allowing multistory shelters to evaluate their capabilities.

Table 3.2-Storm Surge based on Hurricane Category (NOAA, 2005a)

Category	**Storm Surge (ft)**
1	4 – 5
2	6 - 8
3	9 - 12
4	13 - 18
5	> 18

3.6.2 Rainfall

Since the 1970's, inland flooding has been responsible for more than half of all deaths associated with tropical cyclones in the United States (NOAA, 2005c). As a hurricane passes it can dump excessive amounts of rain in a short period of time causing inland flooding.

Determining the amount of rainfall a hurricane will produce is difficult. Unlike storm surge, which is related to wind speeds, the heaviest rainfall might come from a category one hurricane or tropical storm. NOAA (2005c) suggests a crude estimate of rainfall, in inches, for a storm may be obtained by dividing the storm's forward speed (mph) by 100.

When evaluating hurricane shelters, the Flood Insurance Rate Maps (FIRM maps) can be used to identify if a shelter is susceptible to rainfall flooding. Existing shelters should be out of the 100 year MRI and preferable out of the 500 year MRI floodplain

(LOEP, 1997). If the shelter is located within the 100 year floodplain the shelters lowest floor elevation should be compared to the base flood elevation (BFE). A shelter might have been built above the BFE or on localized high grounds. Regardless, the access routs should be checked to determine the expected conditions after the hurricane. If the shelter was built below the BFE or has no access routes after the storm, its use as a hurricane shelter should be evaluated carefully. Otherwise, it is recommended the shelter not be used.

3.7 Wind Load Analysis

To evaluate an existing shelter, the current wind loading codes can be used to determine the expected hurricane wind force. Over the years, the understanding of hurricanes and their wind effects on buildings has increased dramatically. Table 3.3 illustrates this by ranking different building codes based on major changes in wind design and construction standards over the years (LOEP, 1997). Meaning a building built in the 1960's is inadequately designed for wind compared to today's design standards. Comparing today's design standards to the building codes and standards the year the shelter was designed will give an indication of how the building will perform.

To determination of the wind forces on the shelter building ASCE 7 method 2, analytical procedure, or method 3, wind tunnel procedure, should be used. Choosing which method should be based on the building plans, onsite inspection and desired depth of the study. Although use of a wind tunnel test to determine overall pressures on a structure will require more time than method 2, it provides more accurate results. Wind tunnel testing includes effects of surrounding buildings which may provide protection from high wind at critical angles. These reductions in pressures may be enough to avoid major renovation or renovation to only one part of the structure. On the other hand, wind tunnel studies may show an increase in pressures due to local conditions. Besides a reduction in wind loads, structures that have an unusual geometry should be tested in a wind tunnel (ASCE 7, section 6.5.1).

Table 3.3-Ranking of Building Codes for Wind Design (LOEP, 1997)

Model Building Code Ranking					
Model Code(s)	Ranking				
	Promulgation Period				
	Pre-1960	*1960-1976*	*1977-1986*	*1987-1989*	*1990 +*
Southern Building Code (SBC)	0	1	2	3	4
South Florida Building Code (SFBC)	0	2	2	2	2*
Uniform Building Code (UBC)	0	1	2	3	4
National Building Code (NBC)	0	1	N/A	N/A	N/A
Metal Building Manufactures Association (MBMA)	0	0	0	3	3

*-Buildings constructed to SFBC after 1994 are required to comply with ASCE 7. Therefore, they are not considered built to a model code

When using equation 2.1 and 2.2 to determine design pressures, some factors will be adjusted depending on which method is used. Regardless of which method used, the importance factor and wind velocity will be adjusted to comply with the adopted methodology, relating the design to the Saffir-Simpson hurricane scale. Factors related to wind effects, such as the directionality factor, will be adjusted for method 2 but are already included in method 3 when developing the wind tunnel flow conditions.

3.7.1 Exposure Classification

The environment and topography surrounding a shelter can dramatically affect the wind speeds a shelter will receive. Shelters in a dense urban terrain will experience lower wind velocities than those in open terrain. Exposure C, open terrain, will produce higher wind speeds through less interference and low surface friction, where exposure B, dense urban terrain, will be the opposite. The definitions of exposure classifications based on ASCE 7 section 6.5.6.3 are listed below:

- **Exposure B**: To be used in areas where Surface Roughness B is prevalent in the upwind direction for a distance of at least 2360 ft or 10 times the height of the building, whichever is greater, unless the buildings roof mean height is less than or equal to 30 feet, the upwind distance may be reduced to 1500 feet
  Surface Roughness B: Urban and suburban areas, wooded areas, or other terrain with numerous close spaced obstructions having the size of single-family dwellings or larger.

- **Exposure C**: To be used where Exposure B and D do not apply
  Surface Roughness: Open terrain with scattered obstructions having heights generally less than 30 ft. This category includes flat open terrain, grasslands, and all water surfaces in hurricane-prone regions.

As a severe hurricane begins to destroy the surrounding terrain, it is possible that a location originally defined as exposure B might become exposure C. Storm surge analysis might reveal that the once rough terrain will be covered completely in water allowing winds to increase in speed due to fewer obstructions. Although ASCE 7 states that 60% - 80% of buildings are exposure B, for this thesis exposure C should be used if there is any uncertainty. Figures 3.2 – 3.4 illustrate examples of exposures B and C.

The velocity pressure exposure coefficient, K_z, is directly related to the surface conditions around the shelter. As the exposure classification changes K_z will be adjusted accordingly. If a site is located in a transition zone between exposure categories, the category resulting in the largest wind forces shall be used. For wind tunnel testing, a transition exposure can be calculated using procedures from ASCE 7 commentary (ASCE, 2002) or other recognized methods.

3.7.2 Directionality Factor

The directionality factor, K_d, is applied to the design wind speed to account for the probability that the worst winds are interacting with a structure from the worst-case direction.

Figure 3.2-Exposure B Terrain in Foreground Dense Urban Terrain, Unlikely to Change during a Hurricane (ASCE, 2002)

Figure 3.3-Exposure B Terrain that could become Exposure C during an Intense Hurricane due to High Levels of Wind Damage and or Extreme Amounts of Flooding (ASCE, 2002)

Figure 3.4-Exposure C Terrain, Open terrain with Scattered Obstructions less than 30 ft (ASCE, 2002)

When using ASCE 7 for building design the directionality is 0.85, ASCE 7-02, Table 6-4; however, this value was based on non-hurricane prone regions (Ellingwood, et. al, 1980). Easley (2003), states that 0.85 is too low and a higher factor should be used for hurricane prone regions. FEMA 361 and the National Shelter Standards (NSSA, 2001) recommend K_d, = 1.0 for shelters. Easley noted that the use of 1.0 in these publications was primary intended for tornado shelters, which change directions frequently. For hurricane prone regions a directionality factor of 0.95 is recommended by Easley and will be used in this thesis

3.7.3 Design Wind Speeds

The method adopted in Easley to determine design wind velocities will be used. This method allows the selection of wind speeds corresponding to the Saffir-Simpson hurricane classifications, which is more useful to emergency mangers than probabilistic design wind speeds as given in ASCE 7. The Saffir-Simpson scale is based on a one-minute sustained wind, where as, ASCE 7 design calculations are based on a three second gust. ASCE 7-95 (ASCE, 1996) allows for correction of sampling time for hurricane winds using the Krayer-Marshall curve, figure 2.2. Although ASCE 7-98 (ASCE, 1998) and subsequent editions removed the Krayer-Marshall curve from the commentary and recommends using the Durst curve, the Krayer-Marshall curve is still used. Ironically, for hurricane prone regions the ASCE 7-02 design wind speed map, figure 3.5, is based on research from Vickery (Vickery et al., 2000), which uses the Krayer-Marshall curve. Since Vickery's research uses Krayer-Marshall and his findings are used in this thesis, Krayer-Marshall curve will also be used for consistency.

As a hurricane makes initial landfall it will decrease in velocity due to increased surface roughness. In order to account for this initial decrease, maximum values for each hurricane classification from table 2.1 will be used and are presented in table 3.4. For a category 5 hurricane a sustained wind speeds of 190 mph at landfall from hurricane Camille in 1969 were used as an upper bound (NOAA, 2005d). These values represent a hurricanes wind speed at the coast over land for a three-second gust at 10 m height and converted to exposure B through the Krayer-Marshall curve.

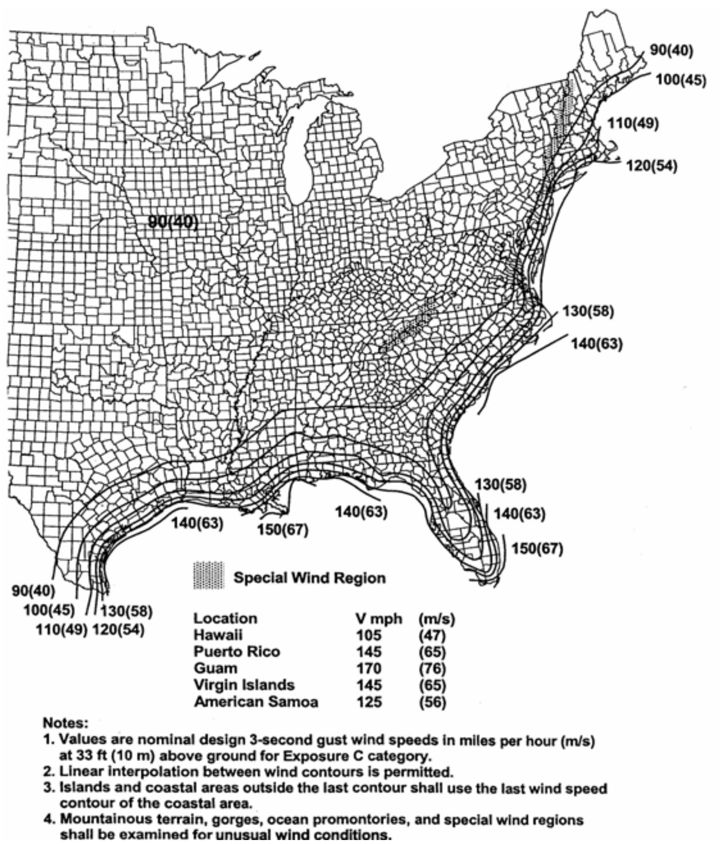

Figure 3.5-ASCE 7-02 Basic Wind Speed Map (ASCE, 2002)

Once a hurricane moves inland it loses intensity and eventually dissipates. Several studies have been conducted on inland decreases of hurricane winds. Easley noted that Ho’s results best-fit the ASCE 7 decrease in design wind speed, see figure 3.5. Although other models include initial decrease in wind speed at landfall, Ho’s tables address this decrease through use of Vickery’s “Maximum Gust Speed Over Land”. Therefore, for this thesis, Ho’s wind speed adjustment factors, table 3.5, will be used to determine the decrease in wind speed over a distance. It should be noted that Ho's values presented in this thesis are for the Gulf Coast region and vary for other regions.

Table 3.4-Initial Wind Velocity after Landfall (Vickery et al., 2000)

Saffir-Simpson Category	**Maximum Three second Gust Over Land**			
	z_o = 0.066 ft (0.02 m) Exposure B		**z_o = 0.1 ft (0.03 m) Exposure C**	
	(mph)	*(m/s)*	*(mph)*	*(m/s)*
1	73	32.7	108	48.1
2	88	39.4	130	58.1
3	106	47.2	156	69.7
4	129	57.8	191	85.5
5	161	72	238	106.4

Using table 3.5, for hurricanes up to a category three in strength, the 85 mb table should be used. For category 4 hurricanes, the 100mb table should be used, and 110 mb table for category 5. Determining the distance a shelter is from the coast should be done using a storm surge map. As a hurricane makes landfall and loses its energy source, storm surge will push the coast back extending the hurricane's energy source. Consequently, it is important to measure the distance a hurricane shelter is from the coast after storm surge; the measurement must be adjacent to the direction the hurricane is approaching.

As discussed in Easley, adjustment factors are more beneficial when presented in distance inland instead of time after landfall. Linear interpolation can be used in table 3.5 when using a known inland distance to determine the adjustment factor. It was also noted that for the Gulf Coast region the average forward speed is around 15 mph (Easley, 2003). Figure 3.6 was developed from table 3.5 with a forward speed of 15 mph and can be used to determine the adjustment factor at a known distance inland.

Table 3.5 Wind Speed Adjustment Factor Using Data Presented by Ho, et al. (1987)

Time After Landfall (Hrs)	**Distance (mi) Based on Forward speed**			**Pressure Deficit at Landfall**		
				Up to 85 mb	**100 mb**	**110 mb**
	5 mph	**15 mph**	**25 mph**	**Wind Speed Adjustment Factor**		
0	0	0	0	1	1	1
2	10	30	50	0.922	0.894	0.863
4	20	60	100	0.861	0.825	0.798
6	30	90	150	0.812	0.775	0.751
8	40	120	200	0.749	0.721	0.701
10	50	150	250	0.706	0.678	0.654
12	60	180	300	0.67	0.64	0.618
14	70	210	350	0.632	0.6	0.572
16	80	240	400	0.592	0.566	0.539
18	90	270	450	0.556	0.529	0.505

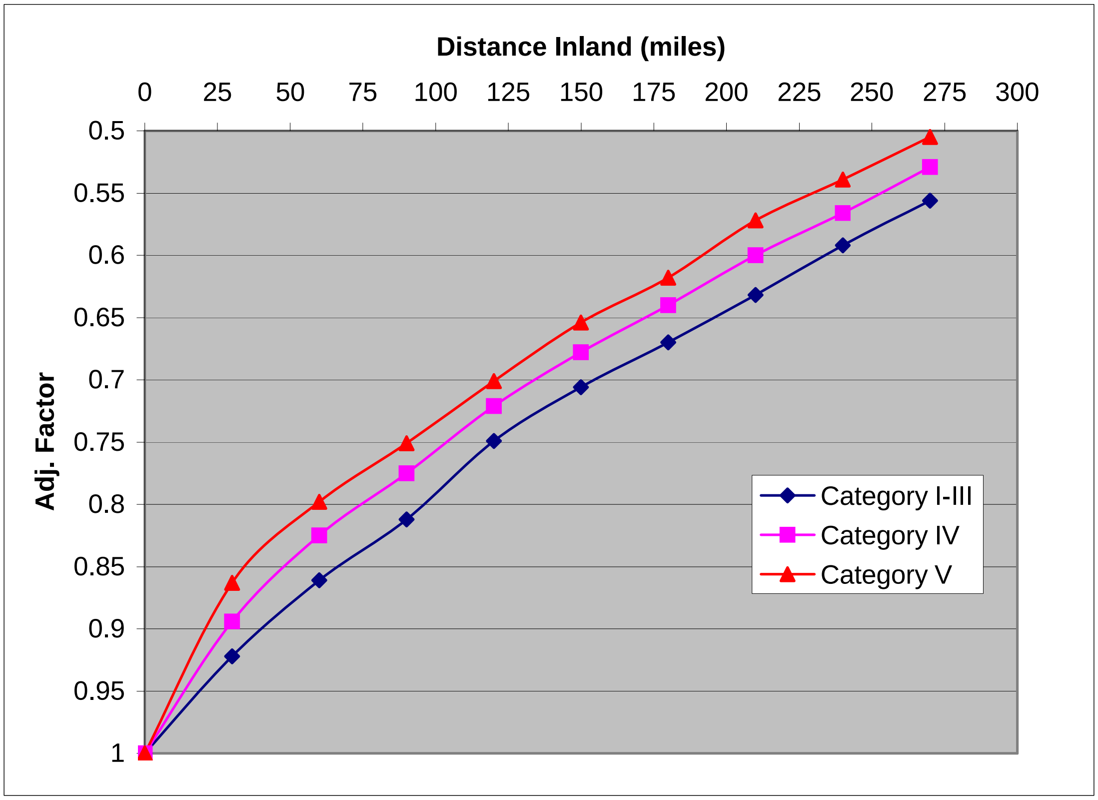

Figure 3.6-Wind Speed Adjustment Factor vs. Distance Inland for a Forward Speed of 15 mph

3.7.4 Importance Factor

The importance factor “I” in equation 2.2 is used to adjust the velocity pressure to account for changes in the mean recurrence interval. Essential facilities and building that represent substantial hazard to human life in the event of failure will have an increased MRI, while structures having low hazard to human life in event of failure qualify for a reduced MRI. ASCE 7 accounts for this by classifying hurricane shelters as a category IV structure (table 1-1), adjusting the importance factor to 1.15 per table 6-1. Changing the importance factor from 1.0 to 1.15 will increase the MRI from a 50 year event to a 200 year event for hurricane regions. Increasing the MRI to a 500 year storm, the importance factor will also increase to about 1.23 (ASCE 7, 2002), vary with location (Easley, 2003). Since design wind speeds are to be selected on the basis of hurricane categories instead of MRI (sec. 3.7.1), the importance factor is not applicable and should be set to 1.0, consistent with recommendations in Easley (2003).

3.7.5 Enclosure Classification

ASCE-7 classifies internal pressure into three groups: open, partially enclosed, and enclosed. The following are the definitions for each classification per ASCE 7 (2002).

- **Open Building**: A building having each wall at least 80% open.
- **Partially Enclosed Building**: In order for a building to be deemed partially enclosed, both of the following conditions must be met:

    1. The total area of openings in a wall that receives positive external pressure exceeds the sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10%.

    2. The total area of openings in a wall that receives positive external pressure exceeds 4 ft^2 or 1% of the area of that wall, whichever is smaller, and the percentage of openings in the balance of the building envelope does not exceed 20%

- **Enclosed Building**: A building that does not comply with the requirement for open or partially enclosed buildings.

FEMA 361 (FEMA, 2000), NSSA (2001) and Easley (2003), all suggest that hurricane shelters be considered as partially enclosed shelters. Hurricane shelters that are not protected against high pressures and wind-borne debris may lose windows, effectively converting an enclosed building to a partially enclosed building. Shelter areas that do not have hurricane protection and have a high risk of being compromised should be evaluated as partially enclosed and not used as a shelter area. Hurricane shelters that have been retrofitted or designed as a hurricane shelter can be treated as enclosed. If throughout the analysis of an shelter it is determined that the shelter will begin to fail at a certain hurricane intensity, that intensity and anything above must be evaluated as partially enclosed. Table 3.6 are the internal pressure coefficients used in equation 2.2 based on the exposure classification.

Table 3.6-Internal Pressure Coefficients for Buildings, GC_{pi} (ASCE, 2002)

Enclosure Classification	**GC_{pi}**
Open Building	0.00
Partially Enclosed Building	+0.55 -0.55
Enclosed Building	+0.18 -0.18

3.7.6 Summary

Summarizing what has been discussed; table 3.7 represents suggested factors for the current shelter design standards, ASCE 7, in one column and recommendations for shelter evaluation based on this thesis in other. The factors recommended for this thesis comply with Easley (2003) and allow an evaluation of design pressures based on the Saffir-Simpson hurricane scale using equation 2.1 and 2.2.

Table 3.7 – Summary of ASCE 7 and Recommended Wind Load Parameter Values for Hurricane Shelters (ASCE, 2002)

Factor	**ASCE 7[1]**	**Shelter Evaluation Recommendations[2]**
Exposure Coefficient, K_z	Table 6-3	Section 3.7.1
Exposure	B or C Section 6.5.6	Section 3.7.1
Topographic Factor, K_{zt}	Figure 6-4	No Change
Directionality Factor, K_d	0.85	0.95
Velocity, V	Figure 6-1a,b,c	Table 3.4
Importance Factor, I	1.15	Section 3.7.4
$G_{(MWFRS)}$	Section 6.5.8	No Change
$C_{p\ (MWFRS)}$	Figure 6-6	No Change
$GC_{p\ (C\ \&\ C)}$	Figures 6-11 - 6-17	No Change
Enclosure Classification	Section 6.5.9	Section 3.7.5
G_{cpi}	Figure 6.5	No Change

[1] table, figures, and section number refer to ASCE 7-02

[2] table, figures, and section numbers refer to this thesis

3.8 Structural Systems Analysis

For shelters that are expected to withstand a category 4 or 5 hurricane completing a structural analysis is essential. Previous building design and methods did not incorporate hurricane conditions and might have been overlooked.

Using the information obtained from the structural plans and onsite inspection a structural model should be created. For complex structures, a finite element program is recommended. After building the model, dead load, live load and previously determined wind pressures are applied to the model to determine the expected stresses, forces, and deflection. Using ACI manuals for concrete design or AISC manuals for steel design, the design values for the members in study will be determined. The expected forces determined from the applied load should be compared to the design values to determine if the building is structurally adequate. If the structure strength is greater than the applied maximum wind then the shelter is structurally satisfactory. If a shelter can not withstand the maximum wind force applied then the failure wind force must be determined. The initial location of failure should also be noted and suggested methods of strengthening should be discussed. If the shelters purpose is to withstand high wind forces and renovations are planned structural analysis should be reevaluated with the proposed improvements. Special attention should be given to the roof when completing a structural analysis, particularly in regions of the roof subject to strong uplift forces.

3.9 Cladding System Analysis

Just as important as the structural analysis, a cladding analysis should be preformed to determine the shelters capabilities against a hurricane. Windows, walls and roof cladding can be broken or removed due to high winds and wind-borne debris exposing the shelter. Cladding failure can lead to structural failure or endanger evacuees and compromise the shelter.

Completing the cladding analysis, material that might have been sufficient when the shelter was built may be insufficient under current design codes. Figure 3.7 is an example of wall cladding that was removed during hurricane Ivan, 2004.

3.9.1 Window Analysis

Using ASTM E 1300, the window glass deflection and failure rate can be estimated. Pressure determined from the wind analysis should then checked against the design pressure. Windows that are under designed compared to current codes potentially can break or be come out of the frame due to excesses deflection. However, if the windows are non-impact resistant and do not comply with ASTM 1986 and 1996 then it can be assumed they will fail once impacted. Therefore, any area that has exterior windows that are not protected from wind-borne debris and do not comply with current standards should not be used.

Figure 3.7-West Florida Hospital Cladding Failure due to Hurricane Ivan, 2004

3.9.2 Water Penetration

Wind driven rain can cause cladding to fail, leading structural failure, as well as making an area unusable. For shelters with soffits, wind driven rain can penetrate inside the shelter creating water damage. It was noticed in hurricanes Charley and Ivan, 2004 that improperly designed soffits under roof overhangs often failed allowing penetration of wind driven rain (FEMA, 2005).

As well, for roofs with high parapets, excessive ponding can occur when drains become clogged or the rainfall rate becomes greater than the design drainage rate. Eventually, ponding can cause the roof to leak and potentially failure. In the event of leaking, water entering the shelter potentially can disrupt electrical systems or compromising shelter area. Figure 3.8 was a shelter area used during hurricane Ivan that could not be used due to the water saturating the insulation and causing the ceiling to fall. Although water penetration may not compromise safety, it can affect usability and increase the cost and time of repair.

Figure 3.8-Water Penetration from Roof Leaks, Hurricane Ivan 2004

3.10 Mechanical Systems Analysis

Some shelters can operate with no electricity where as other, such as hospitals, require it for survival. For shelters that require power to operate, a back-up generator is a necessity. To ensure continuous power throughout a hurricane generators and all components; switchboards, fuel storage etc. must be protected from all hazards; flood, wind-debris. For shelters that potentially can receive storm surge flooding, flood levels determined in the flood analysis should be compared to the elevations that flooding will disrupt the mechanical systems. Any hurricane scenario where the storm surge height will affect the mechanical systems it should be assumed it will not function.

3.11 Shelter Plan

The main idea of this thesis is to combine the flood, structural, cladding, and mechanical analysis creating a shelter plan based on the Saffir-Simpson hurricane scale to be used by emergency managers. The shelter plan identifies different parts of the shelter that are vulnerable to wind and flood hazards and include plans for where to move shelter evacuees to less vulnerable areas. By having a plan on where to place evacuees, a shelter will be able to operate efficiently and be able to make decisive decisions on where to place evacuees during the storm.

After completing the structural, cladding, mechanical and flood analysis, each area of the shelter is classified and placed into one of the four categories, shown below, based on different hurricane scenarios.

- Green –Low Hazard (Preferred Shelter Area)
- Yellow – Moderate hazard (Secondary Shelter Area)
- Gray –Moderate Hazard (Walkways)
- Red – High hazard (should not be used during the storm)

Using a plan view of the entire shelter, areas in the shelter and their hazard level should be separated based on wind and flood and marked accordingly. If an area in the shelter hazard level varies between hurricane categories then there should be multiple wind and flood plans based on each areas hazard. These plans are then combined into a matrix and used in different combinations depending on the various threats posed by the approaching hurricane. Table 3.8 is the Hurricane Sheltering Plan Selection Matrix. This matrix is used to determine which flood or wind sheltering plan should be used, depending on the approaching hurricane’s intensity, direction and tide level.

3.12 Mitigation Plan

The purpose of the mitigation plan is to provide a document summarizing the findings from the flood, structural, cladding, and mechanical analysis and make recommendation to improve the shelter if applicable. With an understanding of the hazards and their potential threat to the shelter, areas of high and moderate hazard can be prioritized based on importance to human life.

Table 3.8 Example Hurricane Shelter Plan Selection Matrix

Category	Direction	Mean Tide Flood Depth Due to Storm Surge (ft)	Mean Tide Flood Plan	High Tide Flood Depth Due to Storm Surge (ft)	High Tide Flood Plan	Sustained Wind (mph)	Peak Gust (mph)	Wind Plan
1								
2								
3								
4								
5								

SAMPLE

The mitigation plan should include a description of current conditions, expected performance levels during a hurricane, and recommendations for improvement for areas of high importance. For shelters that rely on grants or outside funding, the mitigation plan will help obtain the funding by giving an in-depth idea on the cost to upgrade the shelter.

CHAPTER 4: VALIDATION OF WIND TUNNEL TESTING AND MEASURMENT PROCEDURES

4.1 Introduction

In the planning phase of this project, it was decided that West Jefferson Medical Center in Marrero, Louisiana, would be evaluated using the methodology for hurricane shelter analysis of existing structures described in Chapter 3. The hospital's geometric complexity and tall surrounding structures established that wind tunnel tests would be used to determine the pressure coefficients. When this project began Louisiana State University (LSU) was just completing construction of the Boundary Layer Wind Tunnel facility. With this project being the first to use LSU's Boundary Layer Wind Tunnel, its validation will be included as part of this thesis.

Previously and currently used to validate wind tunnels and flow conditions, the Texas Tech Field buildings was chosen to validate LSU boundary layer wind tunnel. Full scale and wind tunnel data were used for the validation study. A 1:50 scale model was chosen based on maintaining an optimal blockage ratio of less than 5% in the LSU wind tunnel and the ability to provide a low Reynolds number with the expected wind tunnel velocities. Additionally, some previous wind tunnel studies reported in the literature also used the same scale.

The results from that test were subsequently compared to full scale and wind tunnel test data on the TTU building reported in the literature. Successfully completing this test demonstrated that proper flow conditions could be met, the instrumentation successfully calibrated, and that the modeling data acquisition, and data analysis components of the wind tunnel test procedure are all working properly. The Texas Tech tests were completed in conjunction with Praveen Kumar and further tests and results can be found in Kumar (2005).

4.2 Texas Tech University Field Building

4.2.1 Full Scale Facility

The Texas Tech University Field Building shown in figure 4.1, is a 9.1 m x 13.7 m x 4 m tall rectangular building located at Texas Tech University in Lubbock, Texas at the Wind Engineering Research Field Laboratory (WERFL). The building was designed and built to study wind effects on a full-scale, simple structure. The building can be rotated and has the capability to measure wind effects through numerous pressure taps. A 48.8m meteorological tower next to the field building records wind speeds at several heights. Over the years, numerous investigators have tested scale models of the TTU field building, comparing their wind tunnel results to full-scale results.

Figure 4.1-Texas Tech Field Building

4.2.2 Colorado State University Wind Tunnel Tests on TTU Building

In 1992, Leighton Cochran, a graduate student at Colorado State University, completed his dissertation conducting wind tunnel tests on 1:50 and 1:100 scale models of the Texas Tech Field Building (Cochran, 1992). This dissertation extensively documented the similarities and differences found in wind tunnel verses full-scale pressures. In order to properly evaluate the models, Cochran rigorously developed boundary layer for the models based on the full scale data from the Texas Tech meteorological tower. Although many other researchers conducted wind tunnel studies of the TTU field building, Cochran's work was perhaps the most comprehensive and most documented study. Therefore, Cochran's study was chosen for comparison of LSU's TTU field building results.

4.3 LSU Wind Tunnel Facility

The LSU Boundary Layer Wind Tunnel (figure 4.2) has a 4.88 m long boundary layer development section followed by a 2.44 m test section that is 99 cm high and 132 cm wide (figure 4.3). A 12 hp fan is located downwind creating a suck down wind tunnel. The 1.8 m long contraction with a 19 cm aluminum honeycomb and screens provide a contraction ratio of 4.5 upstream; creating relatively smooth and uniform flow at the entrance of the boundary layer section. The test section has an adjustable roof, allowing for adjustment to maintain zero pressure gradient along the test section. Centered in the test section is a 129.5 cm diameter turntable supported on an independent frame. Rubber seals are attached under the turntable preventing any air leaks into the test section from the turntable. Spires and an 8.9 cm saw tooth trip were used at the beginning of the boundary layer development section to help create the needed boundary layer. The orientation of coordinates used for the wind tunnel and this thesis is shown in figure 4.4, with the center of the test section being the reference point origin.

4.4 Flow Conditioning

In order to validate the LSU wind tunnel with a 1:50 model of the Texas Tech Field Building, the proper flow conditions had to be obtained. Using Cochran's (1992) studies on

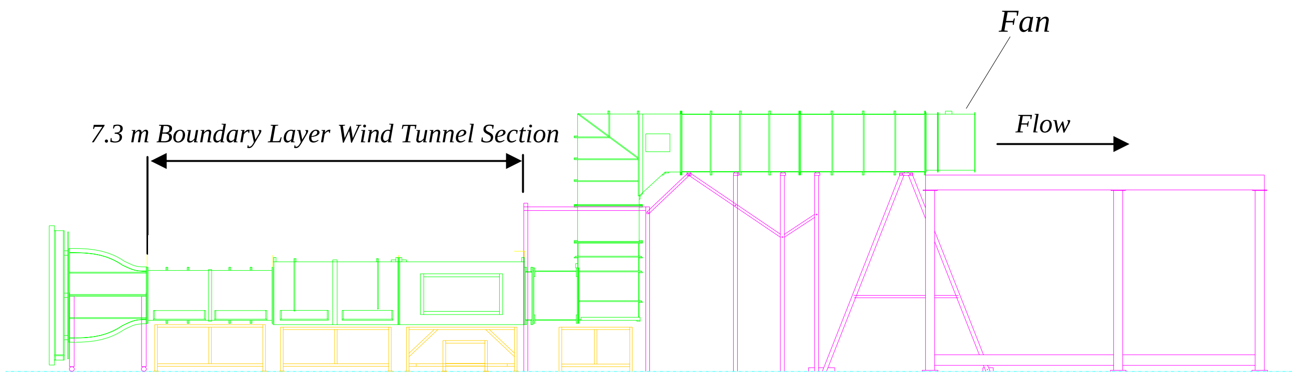

Figure 4.2-Elevation of LSU Wind Tunnel in Boundary Layer Configuration

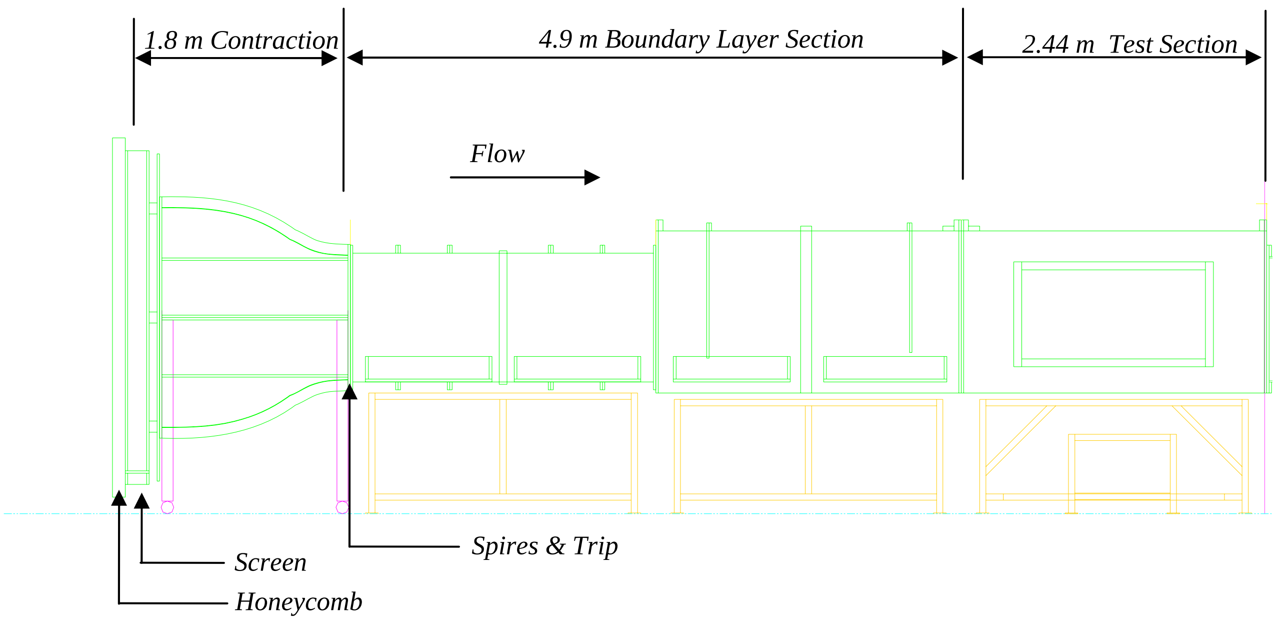

Figure 4.3- LSU Boundary Layer Section

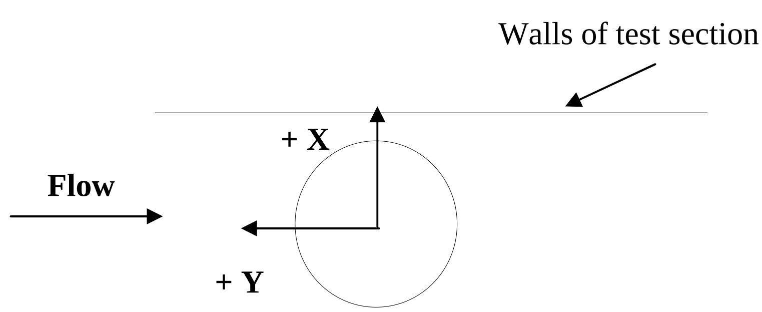

Figure 4.4-LSU Wind Tunnel Orientation of Coordinate Axis. Origin is Located at the Center of the Turntable, which is Centered in the Wind Tunnel. The Z axis is Measured Vertically from the Floor of the Tunnel

the field building, his flow conditioning and the full-scale flow data he used as a guide we developed similar flow conditions.

To simulate the target boundary layer established methods that are commonly used for flow conditioning like spires, trip, grids, carpet, and surface roughness element were tried in combinations of different sizes and arrangements. For each configuration, the velocity profile, longitudinal turbulence intensity, and longitudinal length scale were measured and compared to the target profiles.

4.4.1 Velocity Instrumentation and Data Acquisition

To develop the desired mean profile, turbulence intensity, and longitudinal length scale a thermal anemometer IFA300, also know as a hotwire, was used to record the flow conditions. The hotwire system, manufactured by TSI, has a minute wire or film sensor at a constant heat that records velocity through the voltage change as the wire adjusts for temperature change. As a result a detailed time records of the wind flow can be obtained. The hotwire system was calibrated using Model 1129 Automated Air Velocity Calibrator as recommended by the manufacture. The calibrator uses compressed air to apply a range of low turbulence air velocities. Once calibrated, the calibration data is stored in the computer and referenced when tested.

While recording the flow velocity, the hotwire system had a sampling rate of 5Khz, sampling duration of 128 seconds and a low pass filter of 300 Hz. The probe was placed center of the turntable and measured vertically every 12.7 mm from 25.4 mm to 241.3 mm and 101.6 mm up to 660 mm.

4.4.2 Mean Velocity Profile

Wind speed increases with height above ground due to reduced frictional forces from the earth’s surface. This relationship commonly described by the empirical equation know as the power law, equation 4.1 (Holmes, 2001), where U_z is the mean velocity at height z above ground, Z_g is the gradient height, U_g, the mean velocity at gradient height and alpha is the power law exponent.

$$\overline{U}_Z = \overline{U}_g \left(\frac{z}{Z_g} \right)^{1/\alpha} \qquad [4.1]$$

Knowing the targeted alpha of 6.2 – 6.78 (Cochran, 1992), the gradient height of 274.3 m (ASCE, 2002) was scaled and an arbitrary gradient velocity chosen as a guide. Power law coefficients and other velocity profile parameters for the TTU full scale and model tests as well as values used in design are given in table 4.1. Values are also given for exposure C (flat open terrain) as defined in ASCE 7.

Table 4.1 Terrain Exposure Constants for Texas Tech Field Site

Source	α	$1/\alpha$	Z_o (mm)	TI %
LSU	6.04	0.166	14.2	16
Cochran R2 1:50 (1992)	6.2	0.161	10	25
TTU Field Site (Chok, 1988)	6.78	0.147	13.7	18
ASCE 7, Exposure C	6.5	0.154	20	16.7

To achieve the desired velocity profile, exposure C[1] spires (figure 4.5) shaped like the expected velocity profile were added at the entrance of the boundary layer section to allow the flow to develop and simulate the desired boundary layer, and restrict flow near ground level and gradually increase the amount of flow through the spire as height increases. A 50.8 mm saw tooth trip was also placed 48.2 cm downstream from the spires. Figure 4.6 shows the mean velocity profile for the LSU flow simulation, along with target and reference profiles. The LSU data matched the target profile well.

[1] LSU wind tunnel labeling

4.4.3 Longitudinal Turbulence Intensity

Egg cartons, chains, bricks, and carpet, were all tested in the wind tunnel to try and establish the correct representation of ground level turbulence. For TTU terrain, carpet and a serrated 10 cm trip placed 43 cm downstream from the spires yielded the longitudinal turbulence intensity that most closely matched the target values.

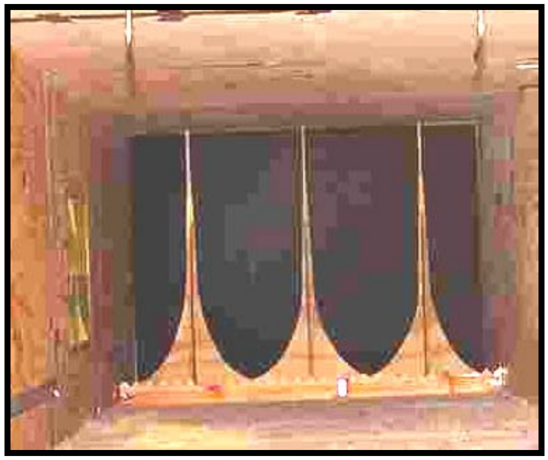

Figure 4.5-Spires for TTU Flow Simulation

For low-rise buildings, matching the target turbulence intensity profile is important, particularly for the range of height of the building. Turbulence above three times the modeled building's height begins to be outside the range that affects the model (Holmes, 2004). The turbulence intensity from the LSU flow simulation comes close to matching the full-scale values at roof height but drops off at higher elevations, as shown in figure 4.7. As an additionally reference, the expected turbulence intensity profile for open terrain is also shown in figure 4.7. This is based on equation 4.2 (Holmes, 2001), with I_u being the longitudinal turbulence intensity, z the height measured, and z_o the roughness coefficient.

$$I_u = \frac{1}{\log_e(z/z_o)} \qquad [4.2]$$

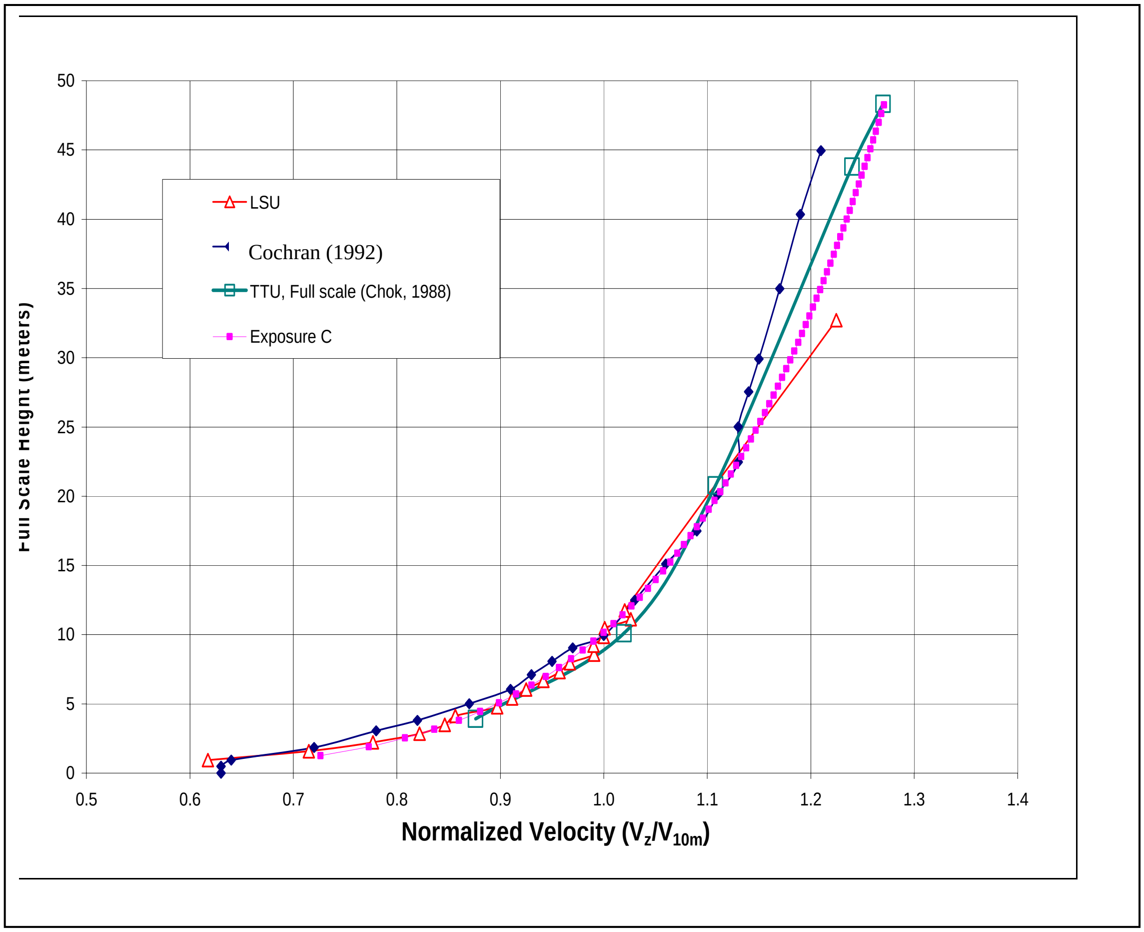

Figure 4.6- Mean Velocity Profile for TTU Flow Simulation

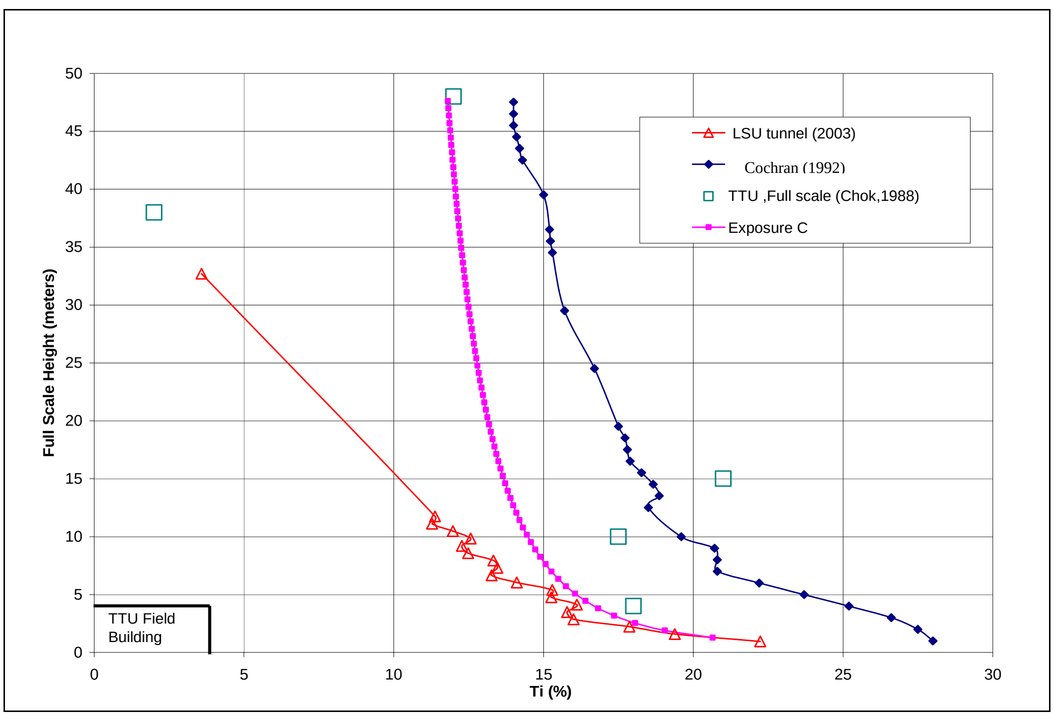

Figure 4.7-Turbulence Intensity Profile

4.4.4 Integral Length Scale

The longitudinal integral length scale was harder to simulate without changing the velocity profile and longitudinal turbulence intensity. Adjusting the trips near the entrance allowed the turbulence to develop throughout the wind tunnel. However, the length scale was small since the ultimate amplitude is limited by the size of test section. Figure 4.8, illustrates the length scale achieved in LSU wind tunnel is lower than Cochran (1992) and the Chok (1988), however, Cochran noted the length scale is of less importance compared to the turbulence intensity and velocity profile and found LSU results to be within an acceptable range (Cochran 2004).

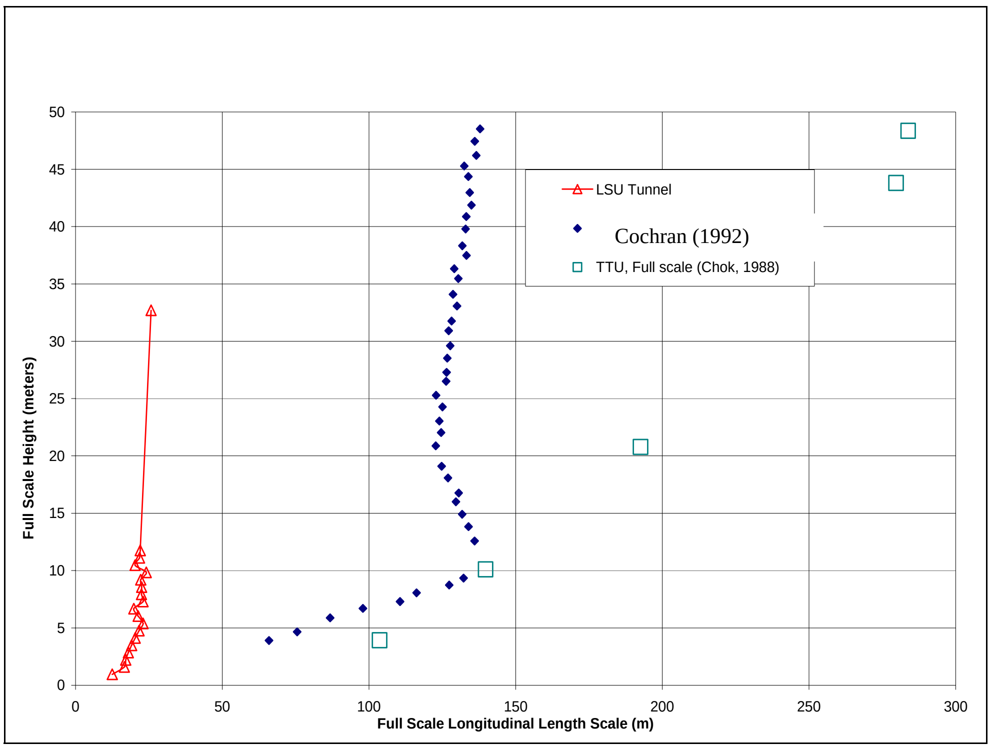

Figure 4.8- Longitudinal Length Scale Profile for TTU Flow Simulation

4.5 Pressure Instrumentation and Calibration

4.5.1 Pressure Instrumentation

A Scanivalve digital pressure measurement transducer, model DSA 3217/3218 was used to measure the pressure data for each pressure tap and the reference pitot tube. The

DSA 3217/3218 has a reference channel and sixteen ports for recording pressures. For all the tests, two pitot tubes were used for monitoring reference velocity, which are located at the same height and same distance upstream away from the model but parallel horizontally. One of these serves as the primary pitot tube and was used for all the experimental result analysis. The results from the secondary pitot tube were kept as a backup set. One of the sixteen channels was dedicated to the reference pitot tube dynamic pressure, and two others to the secondary pitot tube's static and dynamic pressure. The other thirteen channels were used for the pressure taps on the model. The thirteen taps were bundled onto a male coupling and attached to the female coupling when being tested (figure 4.9).

Before each day of testing, compressed air at 90 -100 psi was applied to a calibration port that forced the Scanivalve system to mechanically reset to zero based on atmospheric pressure. A zeroing run with the wind tunnel off was completed before and after each test and the mean of these two runs was used as the zero point for all the channels. Pressure differentials based on the reference pitot tube and taps were collected by the Scanivalve system and raw data then transferred to a spreadsheet.

4.5.2 Pressure Tubing

To fit the channels in the pressure transducer shown in figure 4.9, 1.58 mm inside diameter (ID) tubing was used. One end of the 15 cm long urethane tubing connected the pressure transducer and the other to a female coupling. Fifty centimeters of urethane tubing then connected the male coupling to the model taps. A constant length was used for all tubing. Each pressure tap was drilled with the same ID as the tubing and counter drilled on the inside to hold brass tubing to which the 50 cm tubing attached. Drilling the tap and using brass tubing with the same ID as the rubber tubing allowed for a consistent ID to be kept from the outside wall tap to the pressure transducer.

4.5.3 Dynamic Calibration

Naturally, as wind passes over a wind tunnel model high turbulence or eddies caused by sharp edges will make the surface pressures fluctuate. These fluctuating pressure signals can be decomposed as components with different frequencies. While traveling in the tubing, components at certain frequencies could be amplified, whereas other frequencies could be attenuated.

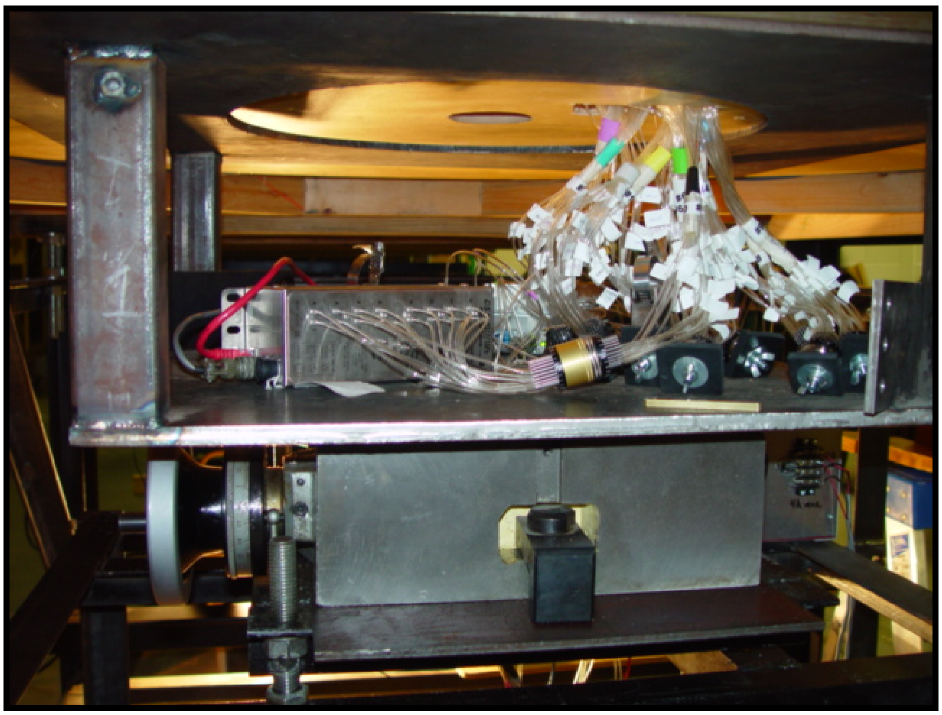

Figure 4.9-Scanivalve, Pressure Tubing, and Connectors

This amplification or attenuation will consequently contaminate the real pressure signal and therefore bias the final results. Ideally, the pressure transducer would be setup just next to the pressure tap, thus a minimum length of connection tubing can minimize this signal contamination. However, it is usually not practical to place the pressure transducer right next to the model in most wind tunnel tests. Many studies have been conducted and one of the solutions to this problem is to use restrictors in the tubing system to achieve a relatively flat response (Holmes, 2001)

For our test, one restrictor, 2 cm long with a 0.4mm ID was attached near the pressure transducer with a second restrictor placed near the female coupling, figure 4.10. The rubber tubing used from the pressure taps to the couple and restrictor had an ID of 1.5 mm.

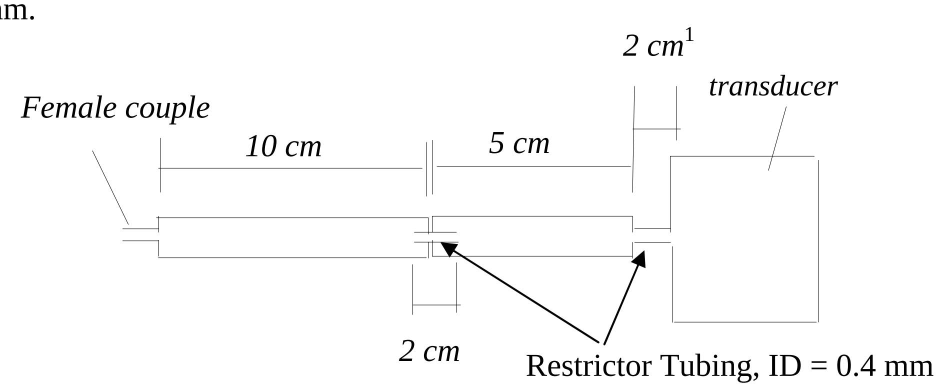

Figure 4.10-Restrictor Assembly Diagram

[1] Restrictor is butted up against transducer and held by urethane sleeve

Figure 4.11 is a photo of the system used for calibration of tubing system dynamic response. The pressure transducer was mounted directly in front of a speaker with an acrylic top. Two taps placed on the same radius from the speaker center were drilled into the acrylic with one tap being directly mounted to the pressure transducer and the other having the full length of tubing used in the experiments. A microphone was also placed in the acrylic to measure the reference pressure amplitude. Comparing the amplitude from the tubing system and microphone at each frequency, the characteristic response curve of the tubing system was established. This curve was then used for further digital correction of all measured pressure signals.

Even with the restrictors, the tubing system can only achieve a relatively flat response up to approximately 100Hz. Although the majority the energy of the pressure signal concentrated at less then 20Hz, a digital correction procedure was adopted to further filter out the tube response contamination based on the calibrated dynamic response curve. It should be noted that majority of the dynamic calibration was conducted by Kirby Hebert. For more information regarding the digital correction, including phase lag and the amplified ratio curve refer to Hebert, (2004) which can be found in Appendix A.

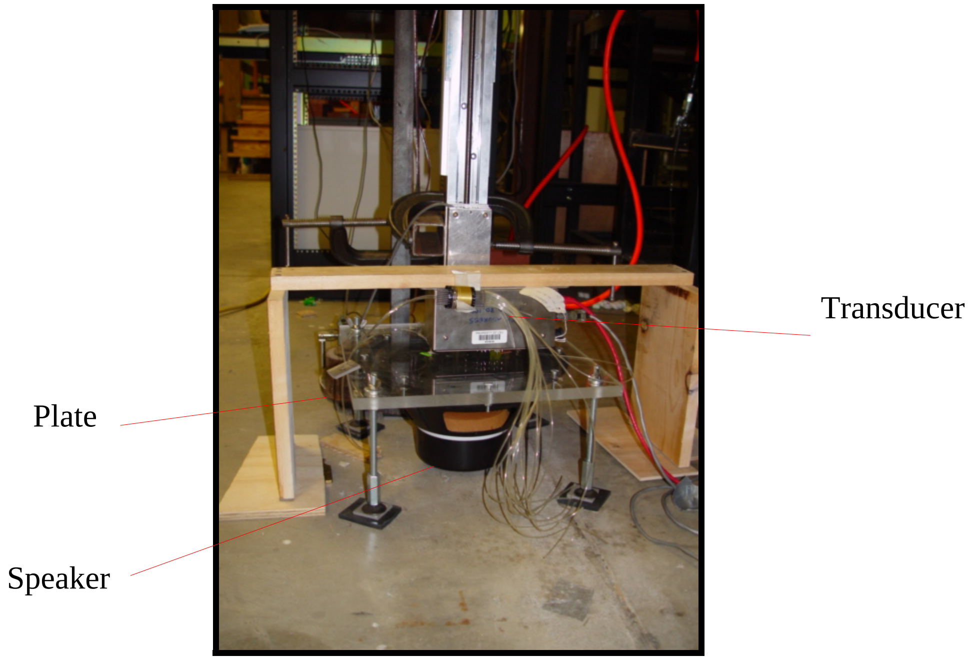

Figure 4.11-Dynamic Calibration Set Up

4.5.4 Reference Velocity and Static Pressure

The pressure measuring system uses a differential pressure. Reference pressure was obtained from the static pressure part of the primary pitot tube used for measureing velocity pressure. The primary pitot tube was positioned at coordinate (-22cm, +1 m, + 76 cm)[1], far enough away from the model to avoid any disturbance of the flow around the model. Static and dynamic corrections were calculated for the model location based on the reference pitot tube pressure location. When the correlation was conducted, the reference pitot tube was simultaneously tested against an identical pitot tube located in the empty test section where the model would later be positioned.

[1] Refer to figure 4.4 for reference coordinates

Two equally spaced pitot tubes were used for all tests in this study. Though, for the test described above, they were utilized differently: one pitot tube was used in comparison with the model, the second was intended as a check (Figure 4.12).

Before testing the model, the two pitot tubes, tubing, and ports used in the pressure measuring system were switched and tested to make sure the system did not have any leaks.

Figure 4.12-LSU Wind Tunnel Duel Reference Pitot Tube System

4.5.5 Data Acquisition and Analysis Procedure

Procedures for acquisition and analysis of wind tunnel data to simulate the TTU Field Building were well documented by Cochran (1992). Using the Scanivalve pressure transducer, pressures were recorded at a sampling rate of 200 Hz for 132 second. The pressure transducer's reference port was attached to the primary reference pitot tube. The data recorded was divided into four segments and a digital, static and dynamic correction applied.

With four 33 second segments the full scale duration equated to four 15 minute segments, resulting in an hourly run. For mean pressures the average of the entire data for a pressure tap at that angle was used. For positive and negative peaks pressures the max and minimum pressures from the four segments were determined and then averaged. Cochran also used this method and he noted the only requirement for using was having a sampling rate greater than 100 Hz.

4.6 Wind Tunnel Arrangement

4.6.1 Wind Tunnel Roof Adjustment

When air passes over a full-scale object, it is forced to go over that object which increases its speed directly above the object. Eventually, these objects develop the full-scale boundary layer by reducing the surface wind speeds and gradually interfering with the wind speeds below the gradient height. Preferably, a wind tunnel would have an unlimited height allowing full boundary layer and atmospheric wind speeds to develop. Dimensional restrictions cannot always allow this to be accomplished. Yet, reducing the model size is not always feasible because small models are difficult to build and test.

Air is allowed to develop into its needed boundary layer in an empty wind tunnel. The boundary layer remains uniform as it passes over the test section. When a several models are placed in the wind tunnel the gradient velocity is affected. To balance this dilemma, the roof in the test section was raised to insure a zero pressure gradient throughout the length of the wind tunnel. The wind tunnel roof with blockage was adjusted to match the roof pressures when the tunnel was empty. Figure 4.13a-c illustrates this concept.

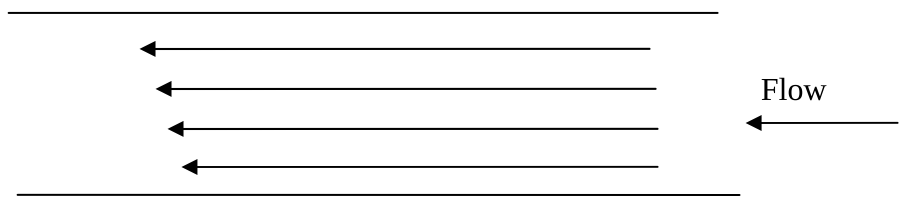

Figure 4.13a-Empty Wind Tunnel with Flat Roof

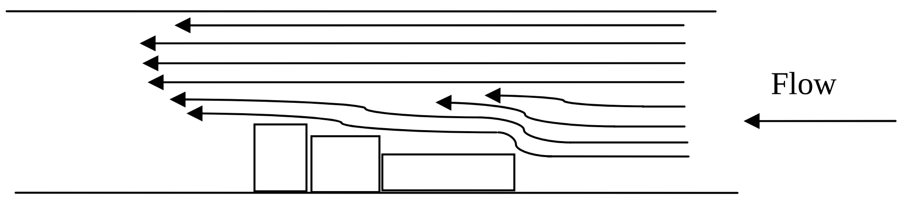

Figure 4.13b-Flat Roof with Models

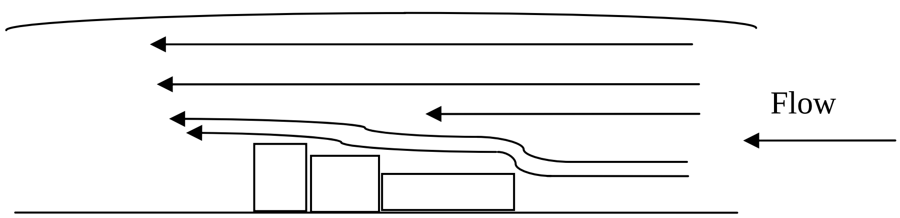

Figure 4.13c-Roof Adjusted with Models

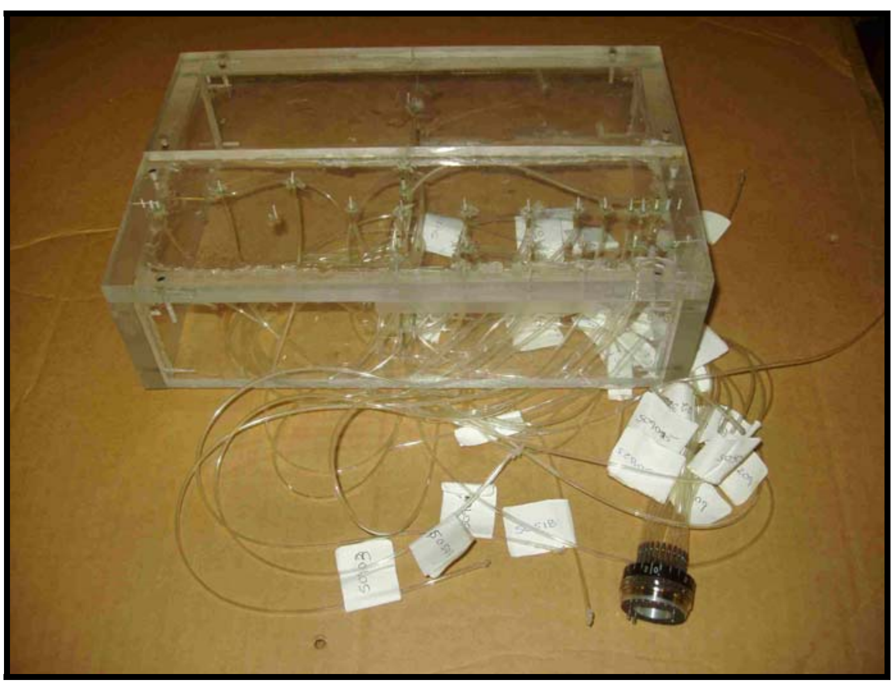

Figure 4.14-LSU 1:50 model of Texas Tech Field Building

4.7 LSU Test of TTU Field Building

Once the correct flow conditions were established, a 1:50 model of the Texas Tech University (TTU) Field Building was built (figure 4.14). The TTU model was made from 12.7 mm thick acrylic and cut to the scaled dimensions discussed in section 4.2.1. The roof of the full scale TTU Field Building had a slight slope for drainage, which was included in the model.

Figure 4.15 illustrates the taps drilled in the TTU model and their orientations. Table 4.2 lists the taps that Cochran (1992) reported, which were measured for peak and mean pressures for comparison. To determine the location of a tap the five digit number reads as follows: The first number represents the section, the next two numbers is the full-scale horizontal dimension and the last two numbers is the full-scale vertical dimension.

Table 4.2-Pressure Taps used for Validation Study

TTU taps	
Sides	*Roof*
11407	50205
22304	50209
31407	50505
42204	50509
42206	50823
42306	50905
	50909

4.7.1 Procedure and Results of LSU Test on TTU Field Building

The wind tunnel maintained a constant wind speed of as the model was rotated every 15 degrees as the pressure transducers recorded the pressures at each angle. The model was tested starting at 0° and ending at 360°, which should corresponds to exactly the same orientation. The results for these two orientations were carefully compared making sure there were not any discrepancies between the beginning and the end of the test, for the

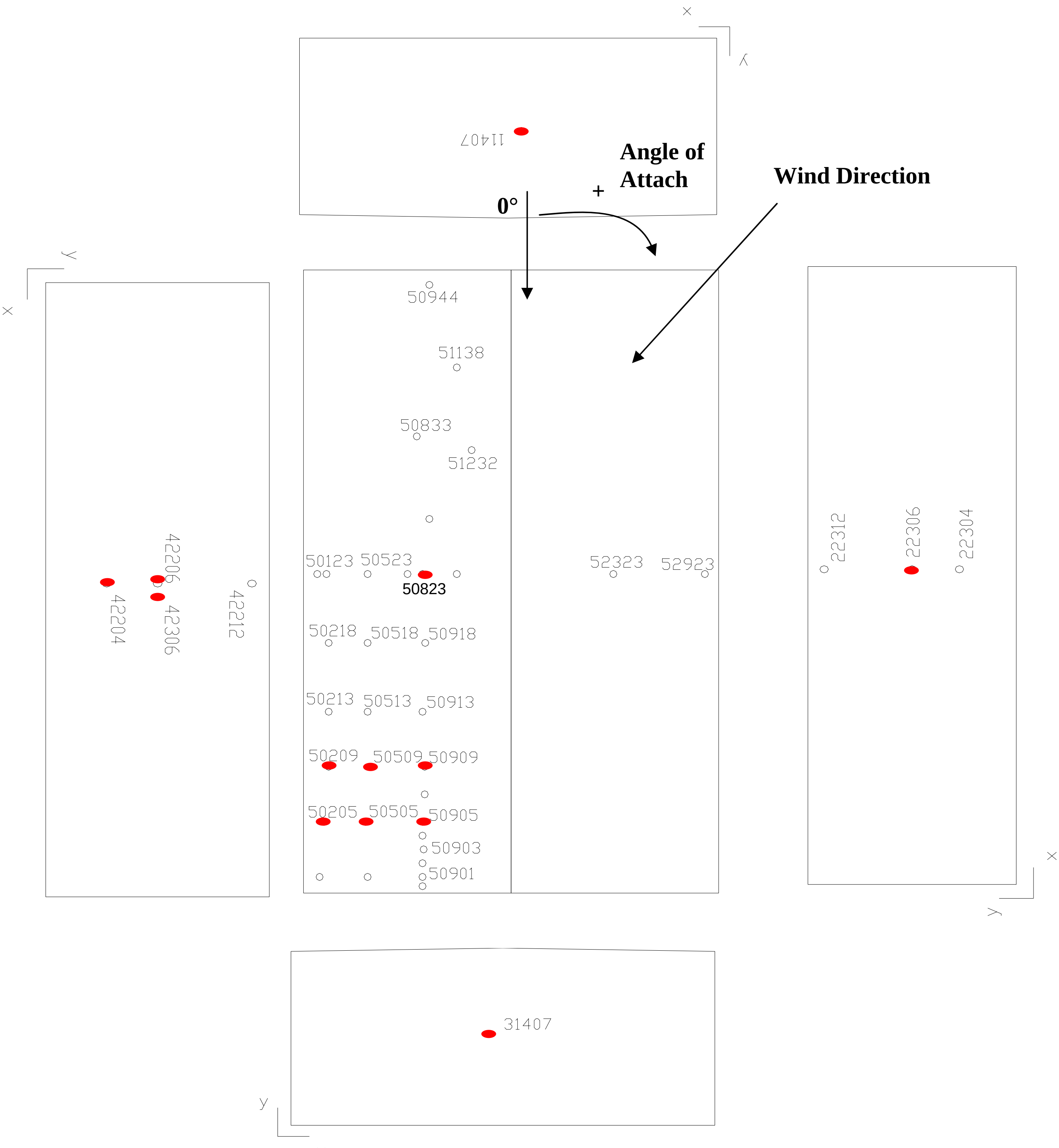

Figure 4.15-Taps in LSU Model of TTU Field Building-Taps Monitored for Validation Study Indicated by Solid Circles

purpose of checking repeatability. Figure 4.16 is the 1:50 model of the Texas Tech Field building being tested in the LSU wind tunnel.

The mean $\overline{C}_p$, positive peak $\hat{C}_p$, negative peak $\check{C}_p$, and the root mean square (RMS) pressures coefficients were calculated and compared to Cochran's 1:50 RII test results (1992) and full scale measurements reported by Cochran (figures 4.17-4.20). 1:50 results from Bienkiewicz (2003) and full scale results from Tieleman (1996) were also reported for taps 50209, 50509, 50909, 50505, and 50905.

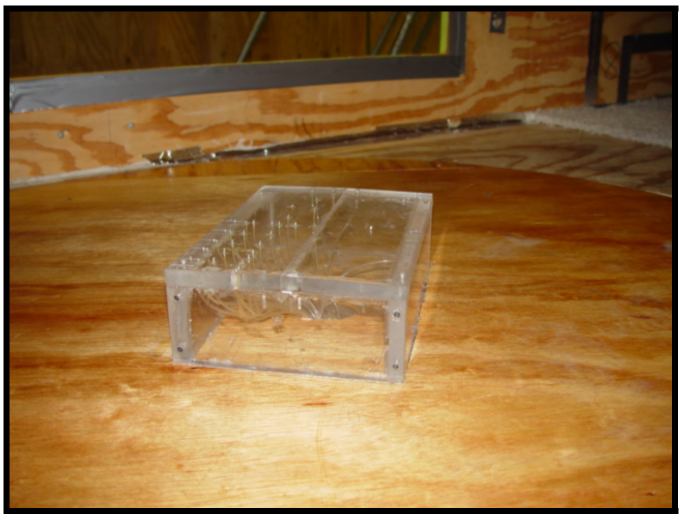

Figure 4.16-1:50 model of TTU Field Building being tested in LSU Wind Tunnel

Results from wall taps matched the closest to Cochran's results. Evaluating the roof pressure taps, the corner taps closely followed the expected results; however the center taps, where the flow reattaches, did not match as well, in certain locations. Comparing these taps to Texas Tech full-scale data presented in Cochran's thesis, LSU center taps matched the full-scale data closely. Peak and valley pressures produced the same comparisons as the mean pressure except LSU's pressure results did not fluctuate as much as Cochran's. This lack of fluctuation in peak pressures can be due to Cochran testing every 5° to 10° where as LSU's test were every 15°. Otherwise, the pressures measured follow Cochran's and full-scale results. For the numerical set of pressure results for the Texas Tech experiment refer to Appendix B.

4.7.2 ASCE Wind Tunnel Testing Requirements

As discussed in section 2.7 ASCE 7 requires that seven conditions be met for wind tunnel testing. Table 4.3 shows the seven conditions and sections they are discussed. All seven conditions were successfully modeled.

Table 4.3-ASCE 7 (ASCE, 2002) Conditions for Wind Tunnel Analysis and Sections Discussed in thesis

Condition	Brief Description	Section Discussed
1	Velocity Profile	4.4.2
2	Integral Length Scale and Turbulence Intensity	4.4.3, 4.4.4
3	Surrounding structures and topography are similar to the full-scale	4.4
4	Model area is less than 8% of the test section area	4.1
5	Longitudinal pressure gradient	4.6.1
6	Reynolds number minimized	4.1
7	Instrumentation is consistent with required measurement	4.5

4.7.3 External Review of Validation Study

After testing the 1:50 TTU model, flow conditioning and pressure results were sent to Dr. Leighton Cochran for review and comments. Cochran noted the length scale was low and felt that was the main contributing factor in the observed difference in roof pressures. To accomplish the correct length scale would require a longer boundary layer section and with majority of taps tested close to expected pressures, he felt the data presented was acceptable. For Cochran's full report refer to Appendix C.

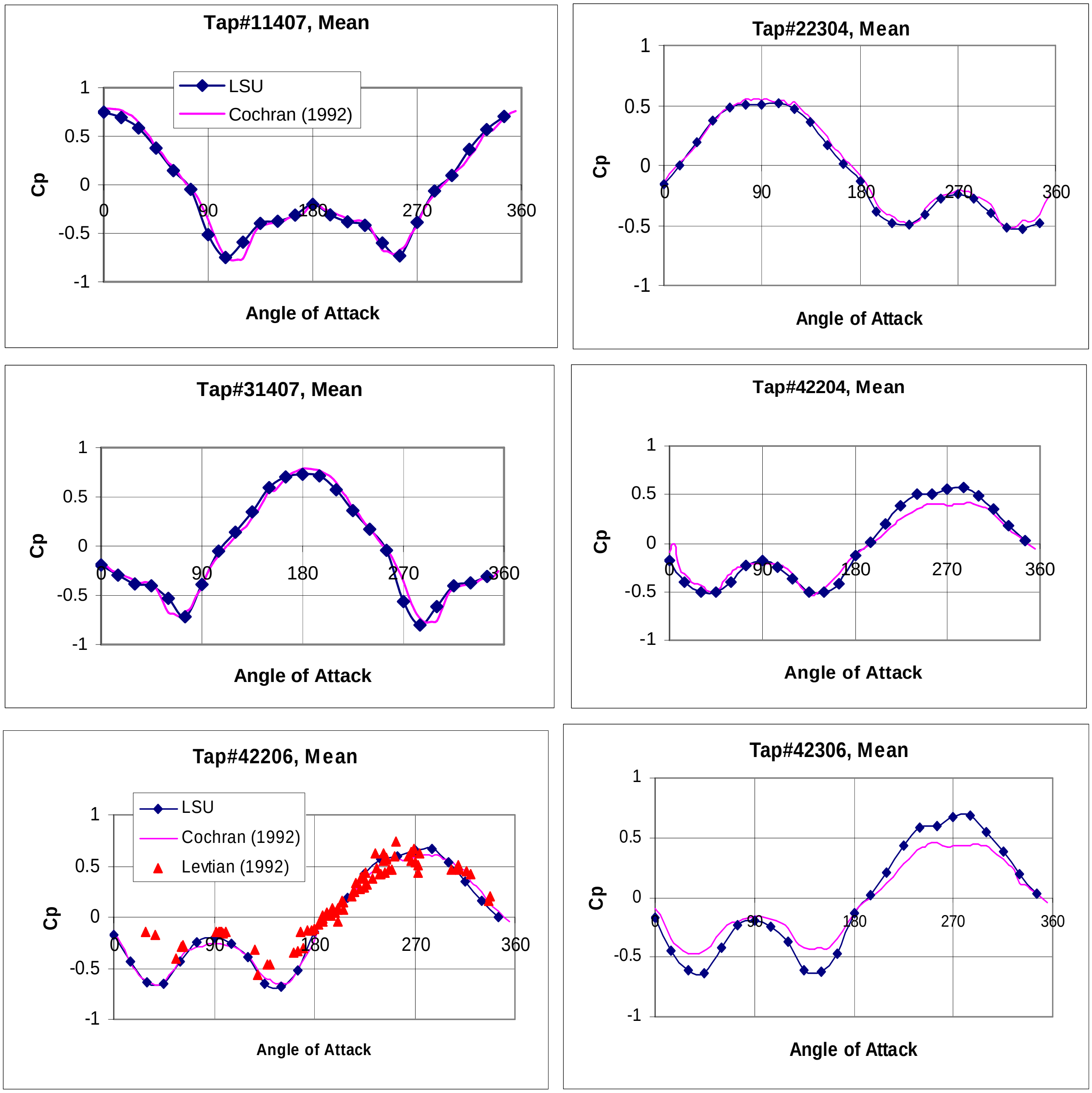

Figure 4.17a-Texas Tech Mean Pressure Coefficients

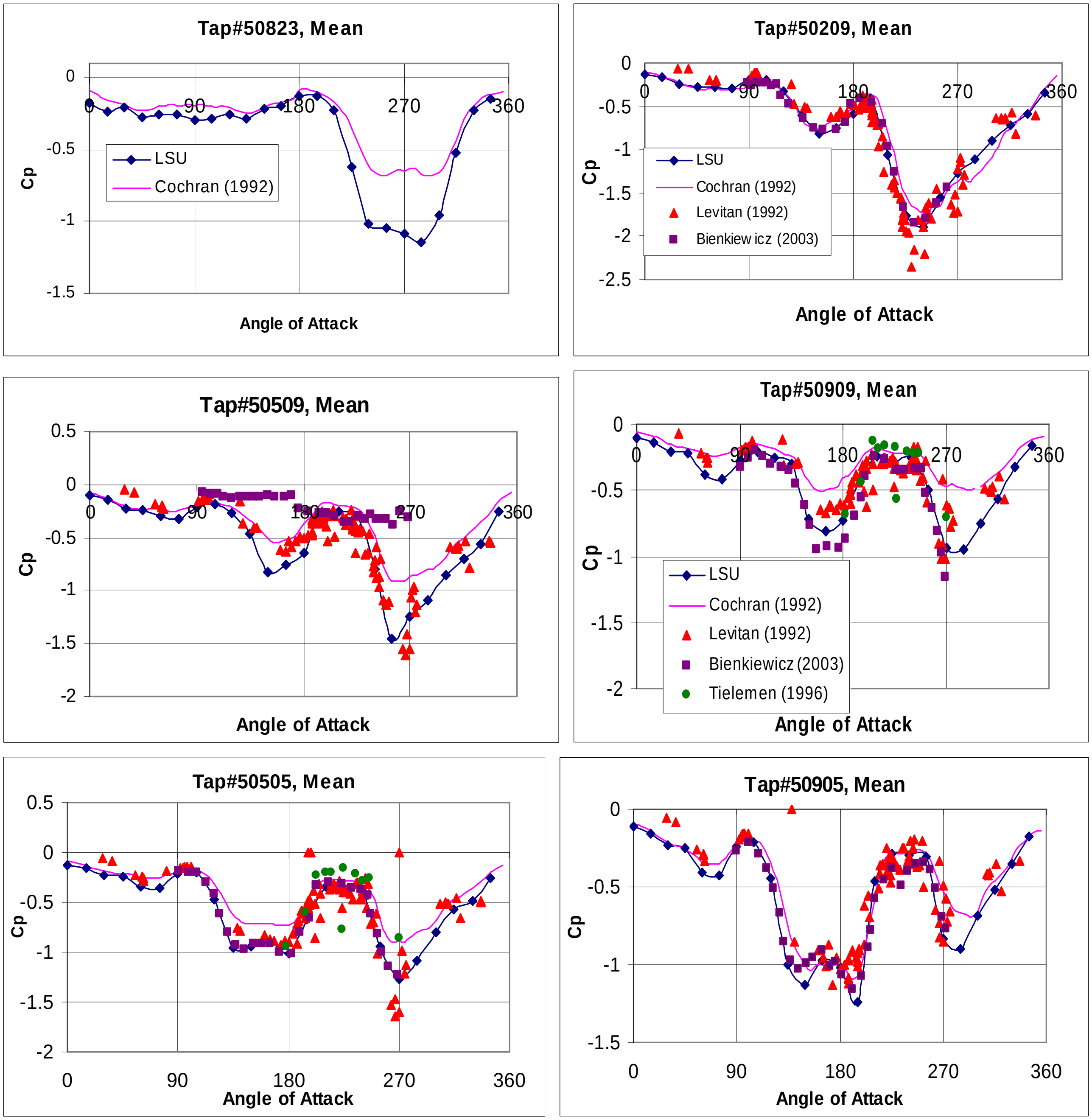

Figure 4.17b- Texas Tech Mean Pressure Coefficients

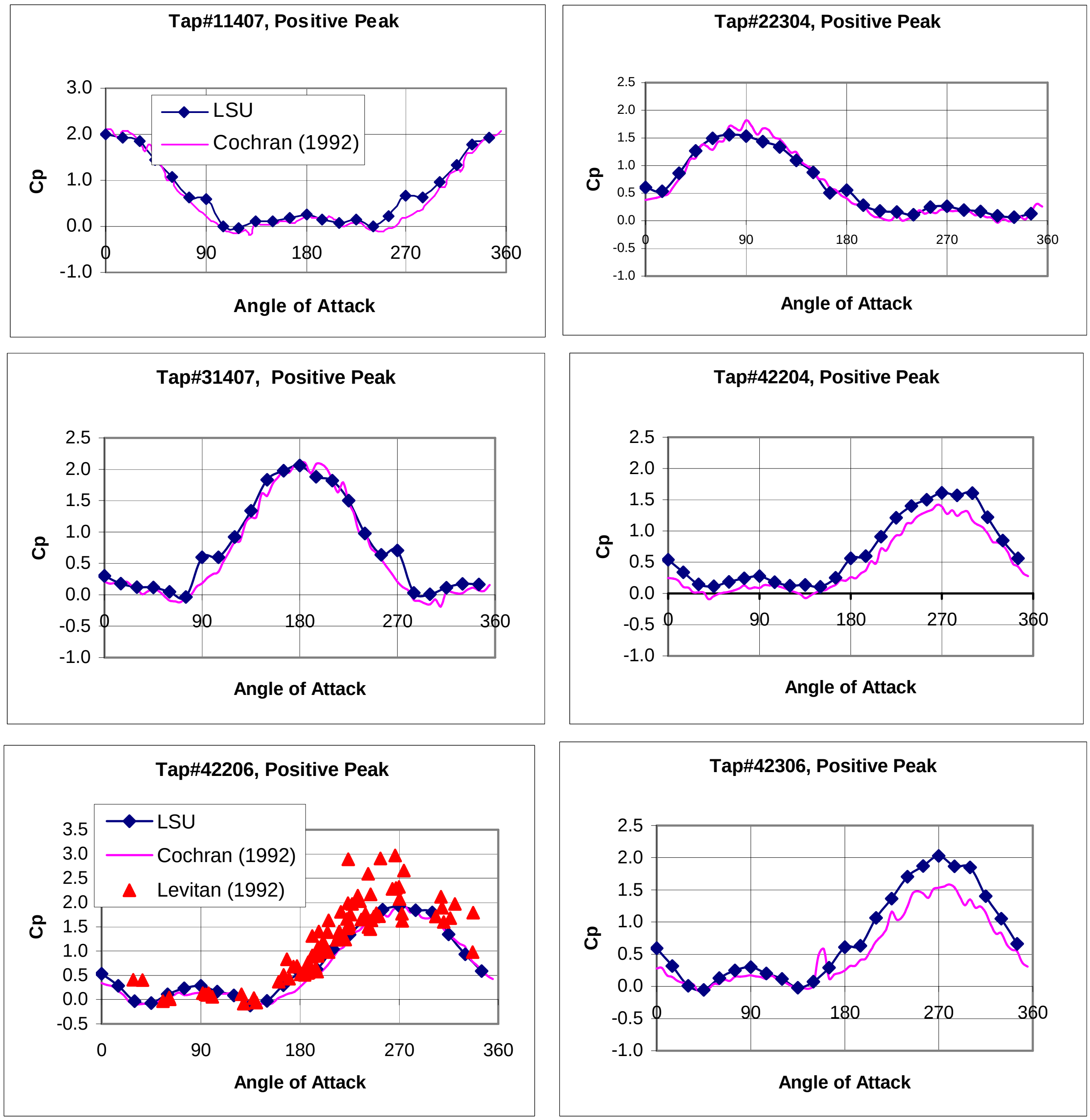

Figure 4.18a-Texas Tech Positive Peak Pressure Coefficients

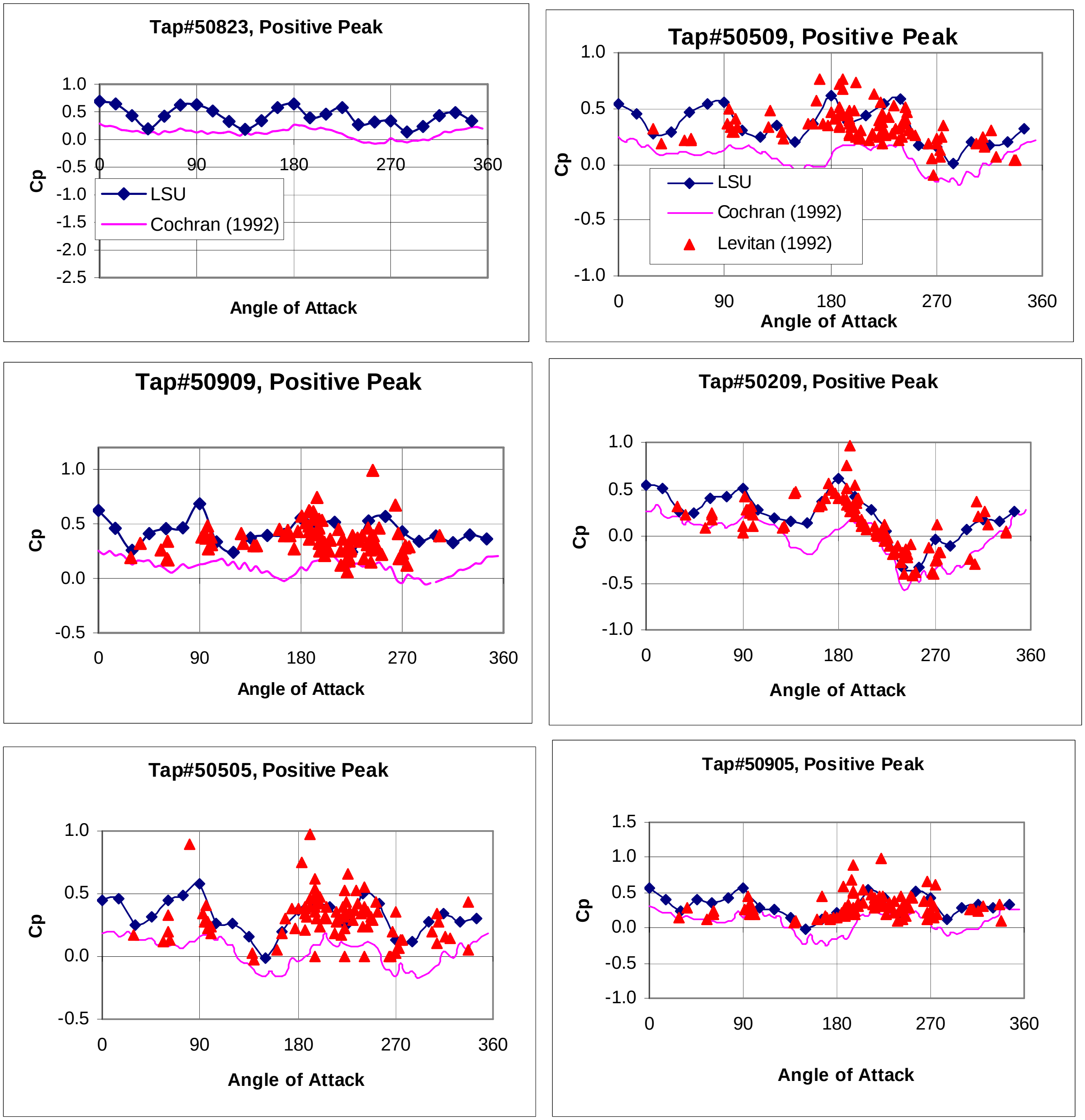

Figure 4.18b-Texas Tech Positive Peak Pressure Coefficients

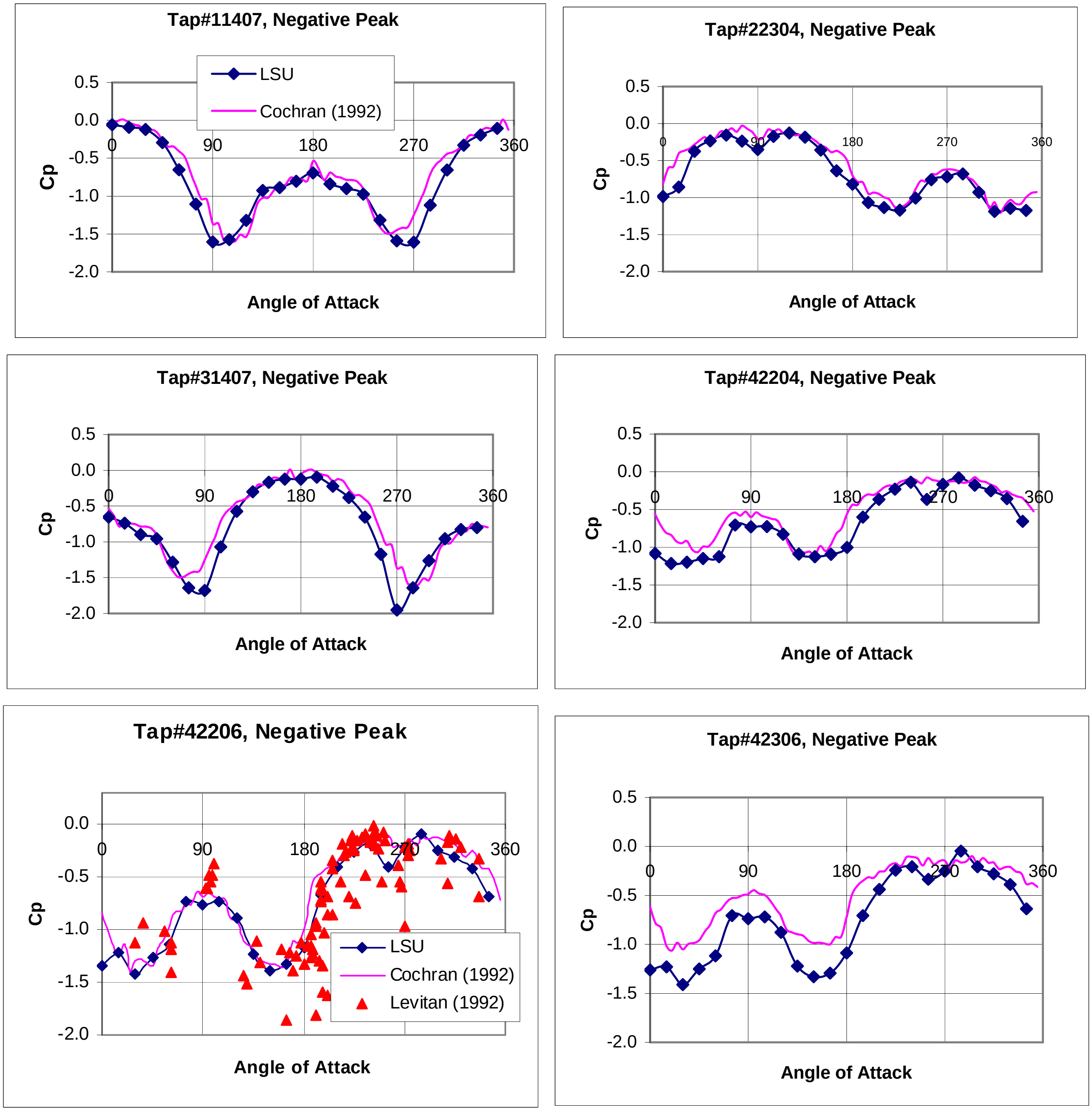

Figure 4.19a-Texas Tech Negative Peak Pressure Coefficients

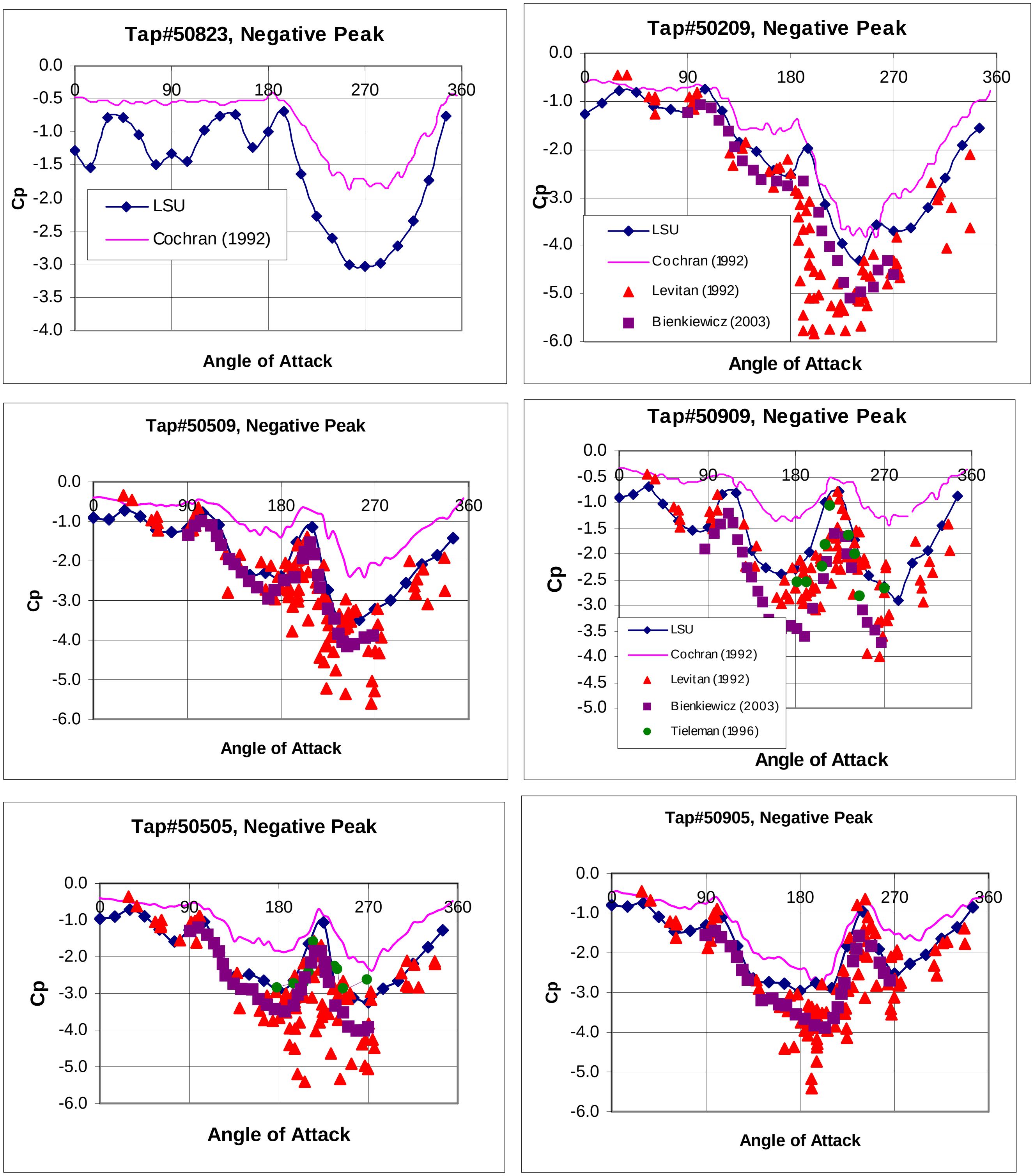

Figure 4.19b-Texas Tech Negative Peak Pressure Coefficients

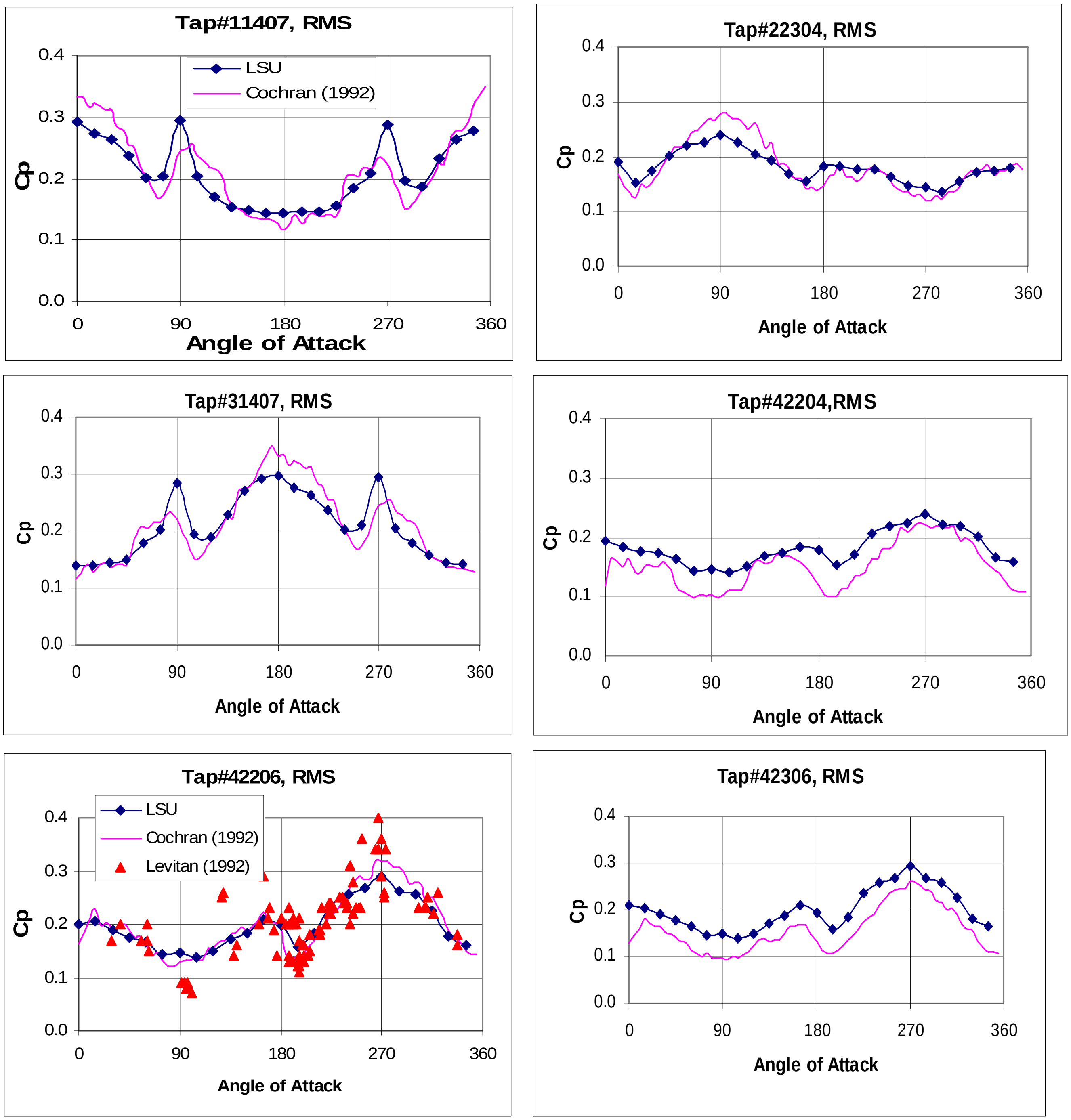

Figure 4.20a-Texas Tech RMS Pressure Coefficients

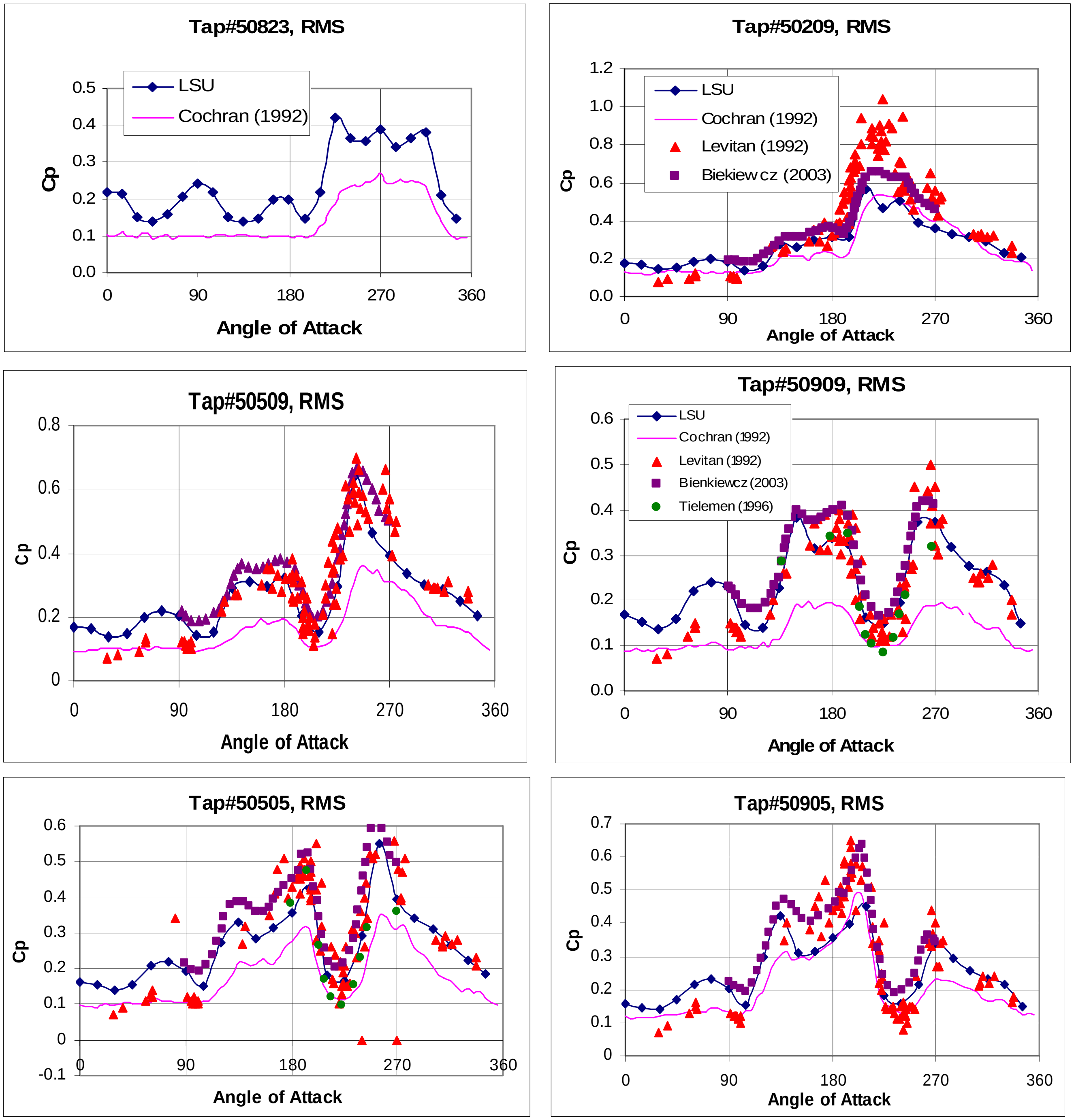

Figure 4.20b-Texas Tech RMS Pressure Coefficients

CHAPTER 5: APPLICATION OF PROPOSED SHELTER METETHODOGY TO ASSESS WEST JEFFERSON MEDICAL CENTER

5.1 Introduction

The West Jefferson Medical Center (WJMC) was evaluated as a case study using the method developed in Chapter 3. The evaluation process to determine the safest place for patients and evacuees to take shelter during a hurricane consisted of an investigation of the clients needs, review of architectural and structural plans of the building to gain an in-depth understanding of the structural systems, and an on-site walk down of proposed shelter areas to further evaluate the composition of their construction and feasibility to function in this role.

5.2 West Jefferson Medical Center

5.2.1 Background

The West Jefferson Medical Center is located in Marrero Louisiana, one mile south of the Mississippi River and approximately fifty miles north and twenty miles northwest of the Gulf of Mexico (figure 5.1). About 10 miles south to southwest from the hospital are the Baritaria swamps, which extend to the Gulf of Mexico. The hospital is located roughly three miles southwest from downtown New Orleans (figure 5.2).

Constructed in several phases, beginning in the early 1960's, over the years the hospital has grown into a campus that includes two ten-story doctor's towers, an eight-story patients wing known as the South Wing, two parking garages, and various other interconnected facilities. Until the late 1970's, Mr. Walter Blessey, P.E., a local civil engineering professor at Tulane University, was the main structural designer and construction engineer for the hospital. During that period he designed and directed the construction of the South Wing, four-story North Wing, and the five-story West Wing.

Figure 5.1-WJMC Relative to the Gulf of Mexico

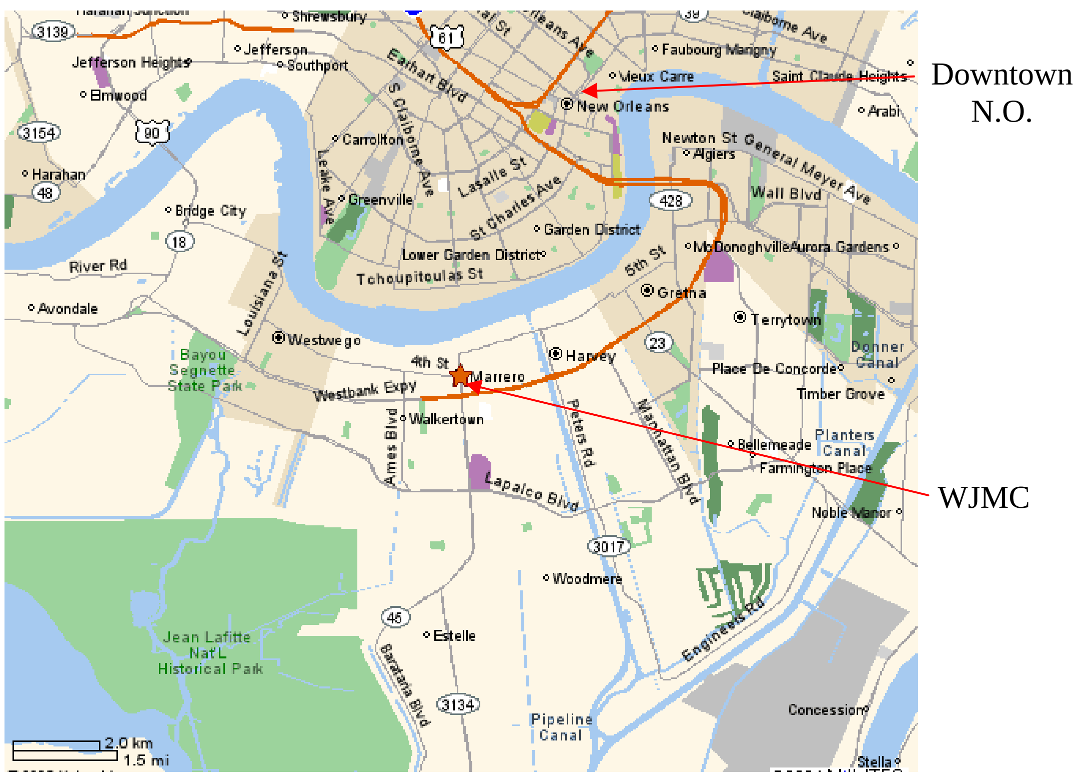

Figure 5.2-WJMC Relative to Mississippi River and Downtown New Orleans

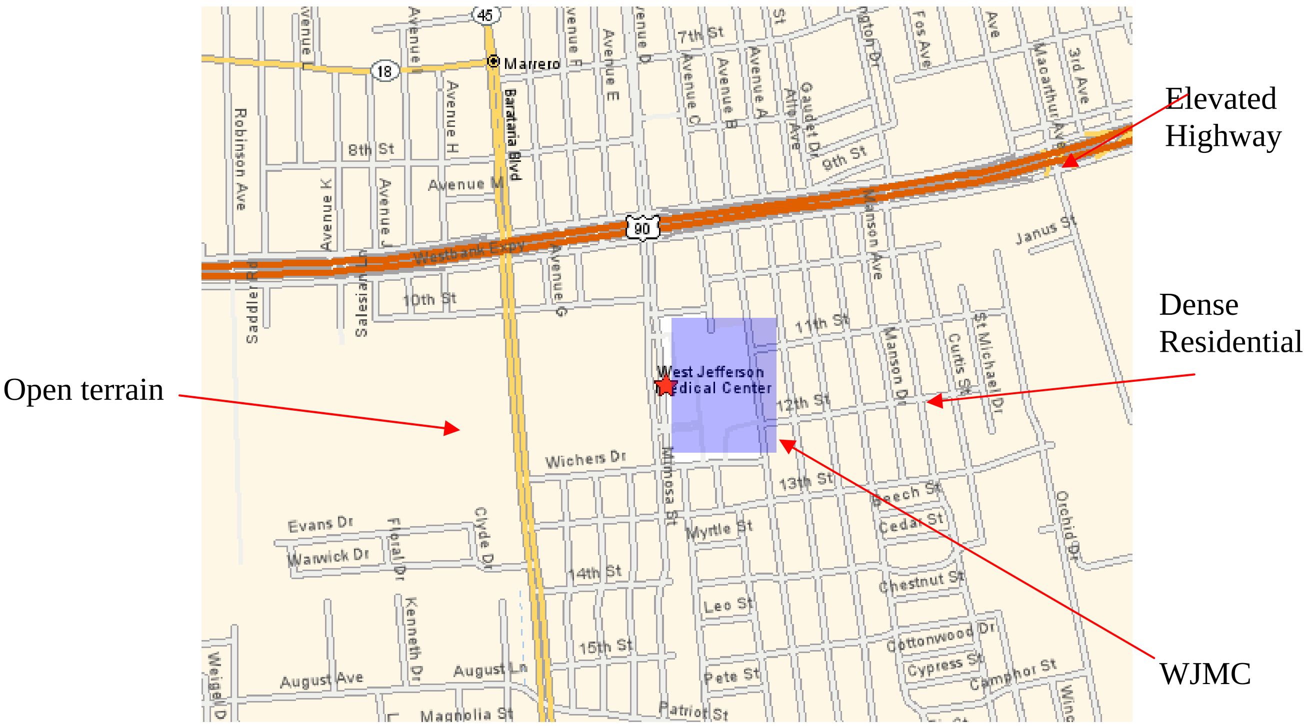

Figure 5.3-Street Map of WJMC

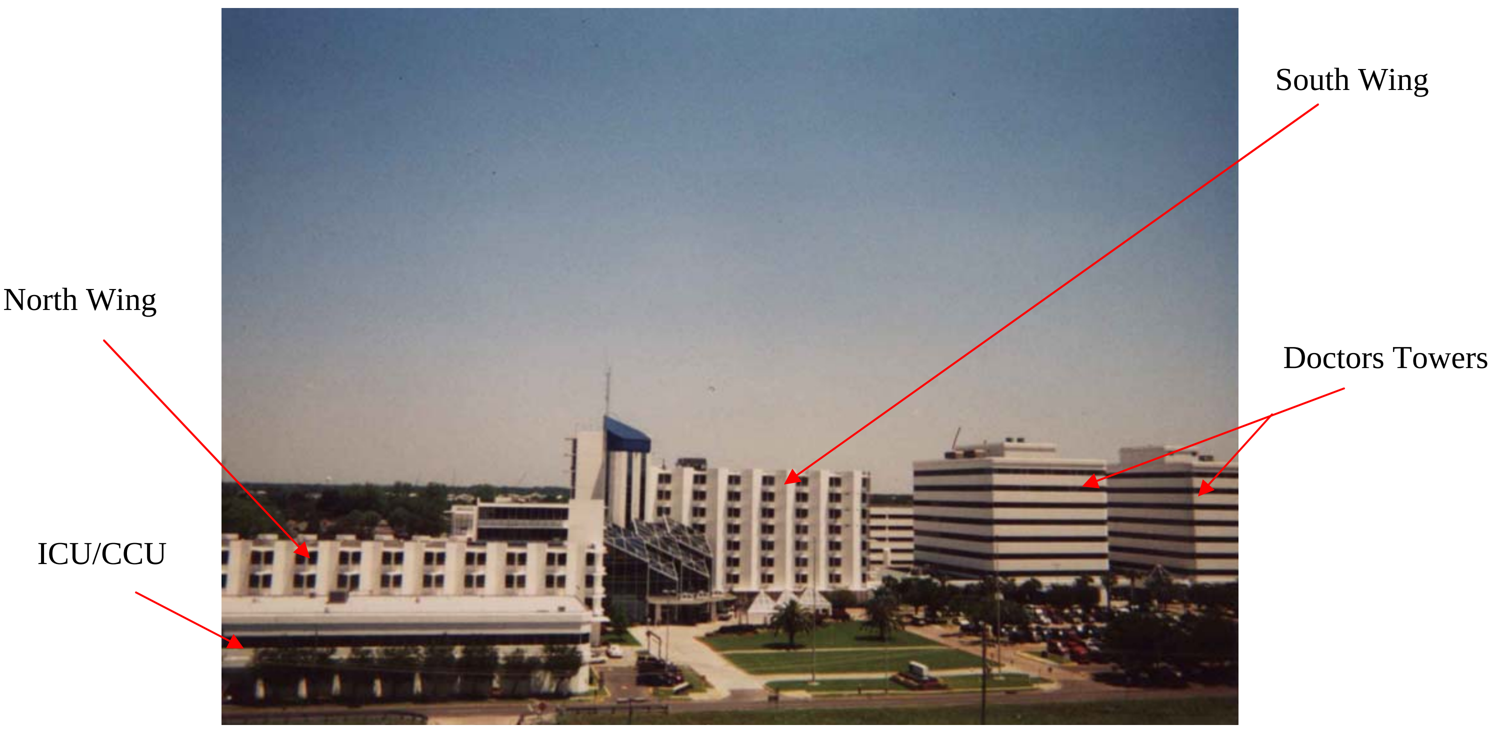

Figure 5.4-West Jefferson Medical Center Looking East

The hospital's ground floor is at an elevation of three feet above sea level, which is considered high in that region of the state. Figure 5.3 illustrates the relative size of the hospital and its surrounding terrain and figures 5.4 and 5.5 are pictures of the campus and South Wing.

Figure 5.5-WJMC South Wing Looking West

5.3 Shelter Needs

After experiencing evacuation of New Orleans during Hurricane Georges in 1998, West Jefferson Medical Center and Jefferson Parish realized the importance of a special needs shelter. From the beginning of this project, WJMC clearly stated they needed to be functional before and after a hurricane made landfall and could not afford to evacuating. Realizing this, the parish and hospital decided to expand their shelter capacity and seek assistance in evaluating their facility for a direct impact from a hurricane of varying intensity levels.

The hospital determined the two ten-story doctor's towers would not be used as a hurricane shelter, and the South Wing would be dedicated as the main shelter area, making it the main focus of the project. Due to the similarities in design and architecture, results from the South Wing would then be applied to the North Wing, West Wing and ICU/CCU buildings and included in the shelter and mitigation reports. Due to the importance, complexity, and geometry of the hospital and availability to sufficient funding, it was decided wind tunnel tests should be conducted to obtain the wind forces. Figure 5.6 is a plan view of the entire West Jefferson Medical Center campus with all the main buildings and their names.

5.4 Building Plans and Specifications Review

With the hospital being built in phases and continually growing, WJMC had over 200 sets of plans. As-built structural, architectural, mechanical plans were obtained for the South Wing. The South Wing was built in two phases with the first four floors built in the first phase. South Wing structural and architectural plans could not be found for phase 2, however, based on conversation with Mr. Blessey (Blessy, 2004) and an onsite inspection, the top four floors were built identical to the bottom floors and plans from phase one were used during construction for all of the South Wing. Reviewing the South Wing's plans, it was noted that the top of first floor slab was at 3 feet above mean sea level, which is consistent with other facilities within the hospital.

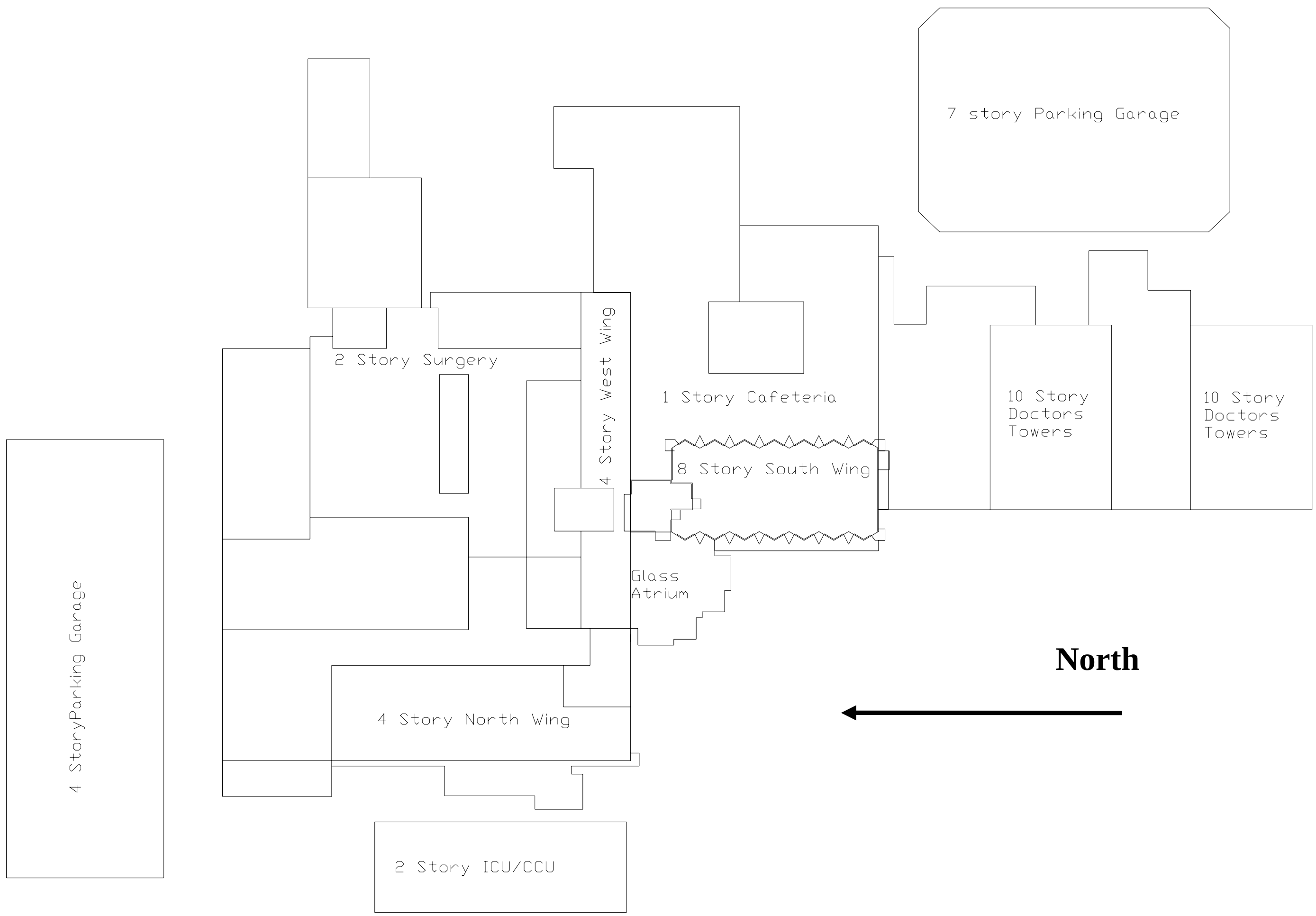

Figure 5.6-WJMC Campus Overview

Overall, obtaining the as-built plans helped grasp a better understanding on the material and construction methods used for the South Wing as well as the remainder of the hospital.

5.4.1 Structural Plans

The South Wing is a reinforced concrete structure with a pan joist floor construction, 13 ft tall first floor; seven 11 ft tall upper floors; and a ten-story elevator and mechanical tower. Above each of the front and rear windows on this structure, a small slab protrudes out from the exterior wall to provide a triangular shaped shade. Reinforced steel was continued from the interior slab into the extended, triangular shaped shade area providing required additional support strength.

The pan and joist system consists of five 4" x 6" interior pans and either a 14" x 6" or 15" x 6" exterior pans that all tie into a 16" x 16" joist, figure 5.7. The joist then distributes the load to the 16" x 16" columns spaced at 12' x 17' lengths, with an overall building dimension of 168' x 51'. The North and South walls are 12" sheer walls, while the East and West wall are 10" pre-cast panels. Being cast-in-place construction, the 3" slab was poured monolithically with the pan joist system.

5.4.2 Architectural Plans

The WJMC architectural plans contained details of exterior cladding members, such as the windows and walls. The South Wing windows have an aluminum frame with non-impact resistant $^{7}/_{32}$" thick annealed glass measuring 60" wide and 138" tall on the first floor and 114" tall on the remaining floors. Although film has been added to the windows, they are still not impact resistant.

5.4.3 Mechanical Plans

Mechanical plans were reviewed to obtain an understanding of the primary and back-up power source. The main portion of the hospital that plans to be used during the hurricane is powered by steam turbines that using natural gas as the source of energy and electricity from Entergy. Back-up diesel generators are located on the ground floor near the steam turbines and will provide power to the necessary areas in the event of loss of the primary power source.

Regardless of the source of power, all power is distributed through control panels located throughout the first floor of the hospital, about 7 feet above mean sea level.

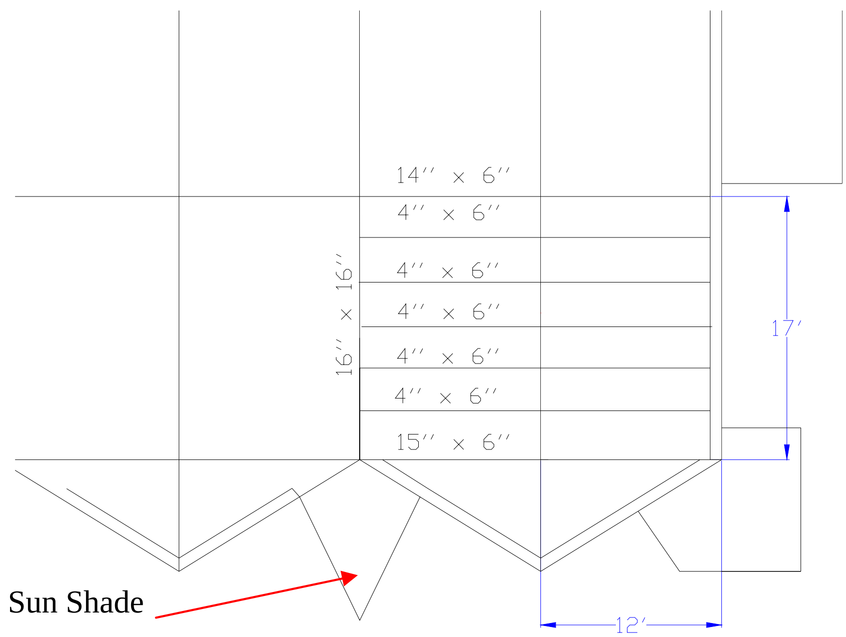

Figure 5.7- South Wing Pan Joist System

5.5 Onsite Inspection

An on-site inspection was conducted several times over the course of the project. The first on-site inspection was conducted of the entire hospital, this provided an understanding of the surrounding terrain, similarities between buildings, and any potential hazards that should be considered.

With the South Wing chosen as the main shelter, areas with external windows, loose roof gravel or debris, and protected interior space were documented. Window type and thickness were noted and the overall condition of the hospital evaluated.

5.6 Flood Analysis

To represent the flood levels and distance the coastline is from the site as the storm surge move inland SLOSH was used (figure 5.8). When calculating the flood levels for the South Wing, the first floor slab elevation, which is 3ft above mean sea level, was subtracted from the SLOSH output, giving the expected flood depth inside the South Wing.

Using the South Wing's latitude and longitude (29:53:33, 90:05:45), mean sea flood levels for a category I – V hurricane approaching due east to west traveling at a forward speed 5 – 15 mph at mean tide were recorded for the South Wing and are presented in table 5.1. It should be noted that the directions shown in table 5.1 are directions the hurricane is heading and the flood levels shown are expected flood levels inside the South Wing.

In a category 1 and 2 hurricane, WJMC site is not affected by storm surge, however, table 5.1 shows that a slow moving category 3 hurricane the South Wing can expect the storm surge to be 0 to 13 ft. With a more intense hurricane, surge levels rise and the faster moving hurricanes that did not flood in a category 3 will. Although the hospital closest direction to the Gulf of Mexico is due East, direction of travel of WNW and W, SLOSH indicates relative low flood levels from these directions. To the South and

Southwest the Baritaria swamps allow the hurricane to push more water into South Louisiana, creating higher flood levels. There was a noticeable jump in the flood levels from a Category II to Category III storm approaching over the Baritaria swamps, directions East to North. This jump is attributed to storm surge topping the levees.

Although the data presented has an accuracy of +/- 20% (NOAA, 2005c), SLOSH makes the assumption that the levees hold and do not break. If the levees near the hospital do break, the SLOSH data for the South Wing will not be correct. For entire set of SLOSH output referrer to Appendix D.

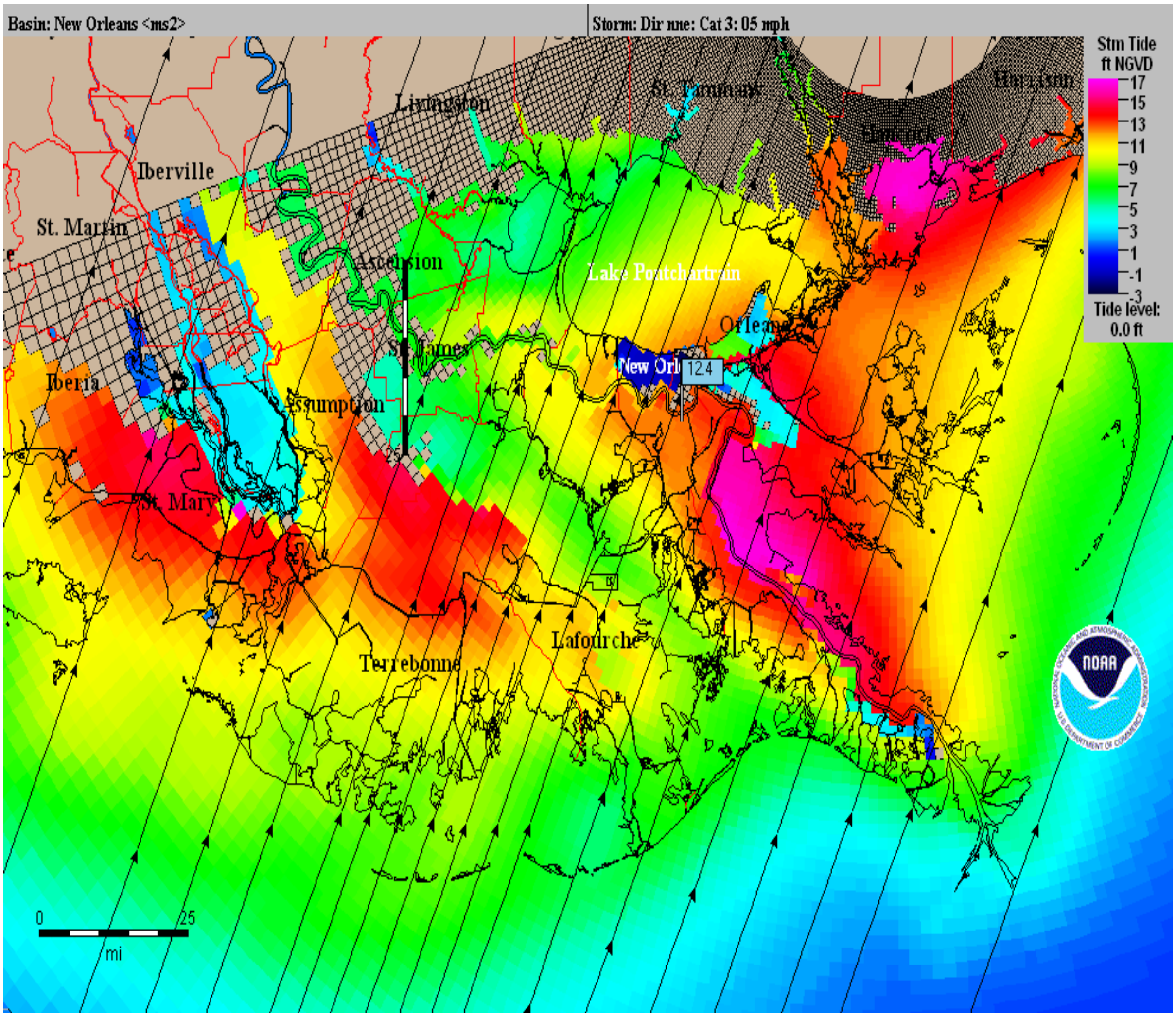

Figure 5.8-SLOSH Model for Cat 3 at Mean Tides Heading NNE at 5 mph

Table 5.1a-SLOSH Results for Cat I-III at West Jefferson Medical Center

CAT 1		
	5 mph mean tide	15 mph mean tide
Direction	Distance from coast (mi)	
E	52	68
ENE	50	56
NE	35	42
NNE	31.1	40.2
N	16	40
NNW	13.1	32
NW	10	30
WNW	9.6	26
W	23	30

CAT 2		
	5 mph mean tide	15 mph mean tide
Direction	Distance from coast (mi)	
E	30	35.9
ENE	30	34
NE	25	36.8
NNE	21.8	30
N	20	15
NNW	10	24.2
NW	9.4	17
WNW	19	21
W	20	27

CAT 3			
	5 mph mean tide		15 mph mean tide
Direction	Dis. from coast (mi)	South Wing Flood Level[1] (ft)	Dis. From coast (mi)
E	Flooded	2.6	50
ENE	Flooded	7.8	37
NE	Flooded	9.1	29
NNE	Flooded	9.4	27
N	Flooded	10.5	15
NNW	Flooded	9.5	16
NW	Flooded	5.7	19
WNW	12	Dry	12
W	12	Dry	20

[1]Flood level inside WJMC South Wing

Table 5.1b-SLOSH Results for Cat IV-V at West Jefferson Medical Center

CAT 4						
	5 mph mean tide		15 mph mean tide		25 mph	
Direction	Distance from coast (mi)	South Wing Flood Level[1] (ft)	Distance from coast (mi)	South Wing Flood Level[1] (ft)	Distance from coast (mi)	South Wing Flood level (ft)
E	Flooded	13.7	25	Dry	41	Dry
ENE	Flooded	15.3	18	Dry	30	Dry
NE	Flooded	15.4	23	Dry	30	Dry
NNE	Flooded	15.5	Flooded	6.3	Flooded	2.9
N	Flooded	14.8	Flooded	8.5	Flooded	4.3
NNW	Flooded	12.2	Flooded	9.8	0	Dry
NW	Flooded	7.6	Flooded	8.3	0	Dry
WNW	7	Dry	7	Dry	7	Dry
W	7	Dry	7	Dry	7	Dry

CAT 5						
	5 mph mean tide		15 mph mean tide		25 mph mean tide	
Direction	Distance from coast (mi)	South Wing Flood Level[1] (ft)	Distance from coast (mi)	South Wing Flood Level[1] (ft)	Distance from coast (mi)	South Wing Flood Level[1] (ft)
E	Flooded	17.6	15	Dry	23	Dry
ENE	Flooded	18.4	Flooded	8.2	18	Dry
NE	Flooded	17.6	Flooded	13.2	Flooded	6.5
NNE	Flooded	17.7	Flooded	15.9	Flooded	10
N	Flooded	17.2	Flooded	16.1	Flooded	10.4
NNW	Flooded	17.1	Flooded	13.3	Flooded	7.9
NW	Flooded	15.9	Flooded	9.9	0	Dry
WNW	Flooded	12	Flooded	11.5	0	Dry
W	Flooded	7.4	Flooded	5.7	0	Dry

[1]Flood level inside WJMC South Wing

CHAPTER 6: WIND ANALYSIS

6.1 Introduction

With the South Wing's geometry being different and not fitting the "box-like" scenario (ASCE, 2002), a scaled model of the South Wing and surrounding facilities were tested in the wind tunnel in order to determine pressure coefficients. Following ASCE 7 method 3, lower limits require the walls, roof, and main wind force resisting system from wind tunnel results not to be less than 80% of design pressures from the analytical method. Therefore, the analytical method should be completed and compared to the wind tunnel results.

6.2 Analytical Method

With one of the main differences between the analytical method and wind tunnel testing being use of surrounding buildings, the 80% lower bound is intended to prevent drastic reduction due to sheltering by a structure that may not always be there. For this project the design pressures from method 2 alone are a minimum compared to the adopted method's design wind speeds. However, as a base to compare results and form an understanding on how the structure will match up under current design codes the analytical method was conducted.

6.2.1 Analytical Method Results

Using the recommendations in table 3.7 for ASCE 7 analysis and equations 2.2 and 2.3, method 2 design pressures were calculated. The values recommended from table 3.7 for the South Wing can be found in table 6.1. Tables 6.2 and 6.3 are the ASCE 7-02 design pressures for the South Wing using values in table 6.1.

Table 6.1-ASCE 7-02 Values for the South Wing (ASCE, 2002)

K_z	ASCE 7 Table 6-3, Exp. B
Exposure	B
K_{zt}	1.0
K_d	0.85
V	131
I	1.15
Enclosure	+/- 0.18
G	0.85
Mean Roof height (ft)	92

Table 6.2a-ASCE 7-02 Method 2 Main Wind Force Resisting System Results

Windward Wall				
Height (ft)	q_z (psf)	q_h (psf)	P (psf)	
15	24.5	41.5	8.7	23.7
20	26.6	41.5	10.1	25.1
25	28.3	41.5	11.3	26.2
30	30.1	41.5	12.4	27.4
35	31.3	41.5	13.3	28.2
40	32.6	41.5	14.1	29.1
45	33.7	41.5	14.8	29.8
50	34.8	41.5	15.5	30.5
55	35.6	41.5	16.1	31
60	36.5	41.5	16.7	31.6
65	37.4	41.5	17.2	32.2
70	38.2	41.5	17.8	32.8
75	39.1	41.5	18.4	33.3
80	39.9	41.5	19	33.9
85	40.6	41.5	19.4	34.3
90	41.2	41.5	19.8	34.7
92	41.5	41.5	20	34.9

Table 6.2b-ASCE7-02 Method 2 Main Wind Force Resisting System Results

Leeward Wall		Side Wall	
P (psf)		P (psf)	
-24.6	-9.7	-31.5	-16.5

Roof				
Distance	Cp		P (pfs)	
			Min	Max
0 - H/2	-1.17	-0.18	-47.6	1.3
H/2 - H	-1.3	-0.18	-52.1	1.3
H - 2H	0	-0.18	-13.6	7.5
>2H	0	-0.18	-13.6	7.5

Table 6.3a-Method 2 Components and Cladding Results

Windward Wall

Height (ft)	q_z	q_h	Pressure (psf)			
			zone 4		zone 5	
30	30.1	41.5	-34.2	34.1	-60.4	34.1
35	31.3	41.5	-35.4	35.2	-62.7	35.2
40	32.6	41.5	-36.5	36.4	-65	36.4
45	33.7	41.5	-37.5	37.3	-66.9	37.3
50	34.8	41.5	-38.4	38.3	-68.8	38.3
55	35.6	41.5	-39.2	39	-70.3	39
60	36.5	41.5	-40	39.8	-71.8	39.8
65	37.4	41.5	-40.7	40.6	-73.3	40.6
70	38.2	41.5	-41.5	41.3	-74.8	41.3
75	39.1	41.5	-42.3	42.1	-76.3	42.1
80	39.9	41.5	-43	42.8	-77.8	42.8
85	40.6	41.5	-43.6	43.4	-79	43.4
90	41.2	41.5	-44.2	44	-80.1	44
92	41.5	41.5	-44.4	44.2	-80.6	44.2

Table 6.3b-Method 2 Components and Cladding Results

Leeward & Side Walls Wall			
Pressure (psf)			
Zone 4		Zone 5	
-44.4	44.2	-80.6	44.2

Roof					
Pressure (psf)					
Zone 1		Zone 2		Zone 3	
-61.1	-46.1	-96.6	-81.7	-132.1	-117.2

6.3 LSU Wind Tunnel Tests

6.3.1 Scale

With a large campus of buildings that potentially could provide shielding for the South Wing, the surrounding buildings were used during the tests. Trying to fit the surrounding buildings and not make the model to small a scale of 1:200 was chosen. The scale chosen provided an acceptable blockage ratio and with the wind tunnel roof adjusted there was a zero pressure gradient.

6.3.2 Flow Conditioning

Due to the wind tunnel being 129.5 cm wide and the desire to include surrounding buildings in the test, the South Wing had to be off centered on the turntable. When determining the flow conditions, not only was the center of the turntable tested for the proper flow, but areas where the model would be throughout the test as well. Figures 6.1-6.3 are the flow conditions for 1:200 exposure B simulations used for the West Jefferson Medical Center tests. The mean velocity profile, longitudinal turbulence intensity, and longitudinal length scale all were successfully developed and matched within the acceptable range. Table 6.4 contains the targeted and actual coefficients achieved in the wind tunnel. For wind tunnel orientation refer back to figure 4.4.

6.4 Scaled Model of the South Wing

The South Wing's concrete window shades (see figure 5.7) made constructing the scaled model tricky. To create the desired geometry, acrylic and stainless steel were cut to the buildings outline and stacked. The stainless steel was cut to match the window shades with the steel thickness matching scaled window shade thickness. The acrylic was

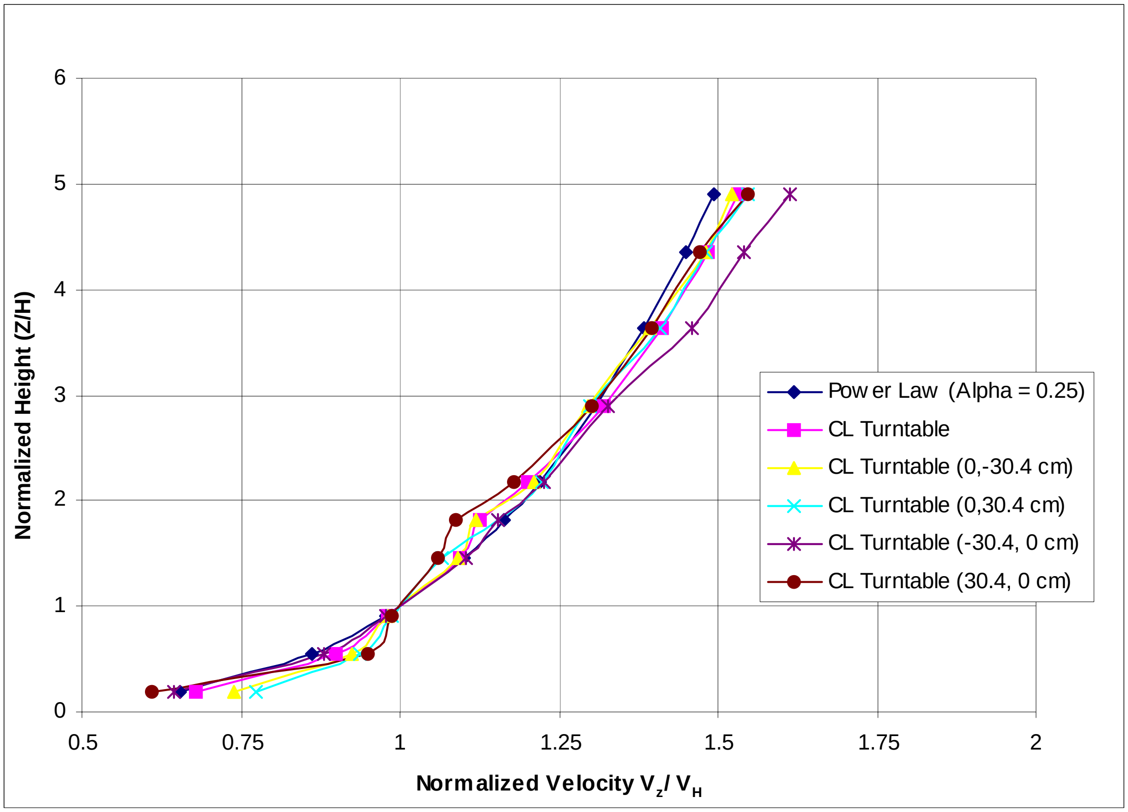

Figure 6.1-Targeted vs. Actual Velocity Profile

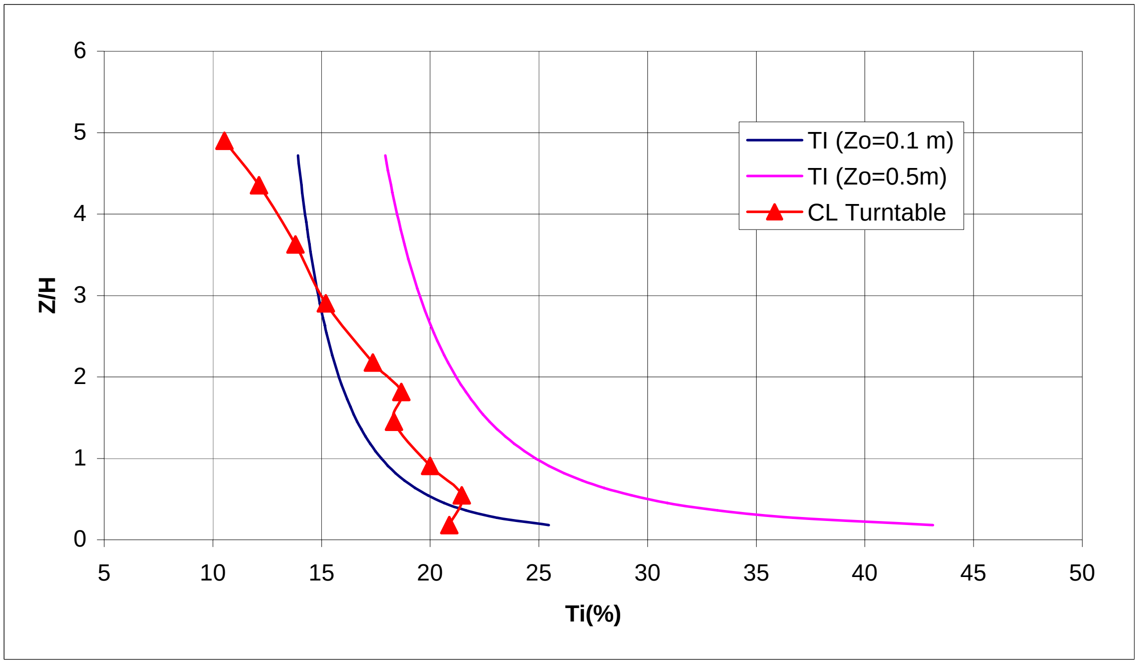

Figure 6.2-Targeted vs. Actual Turbulence Intensity

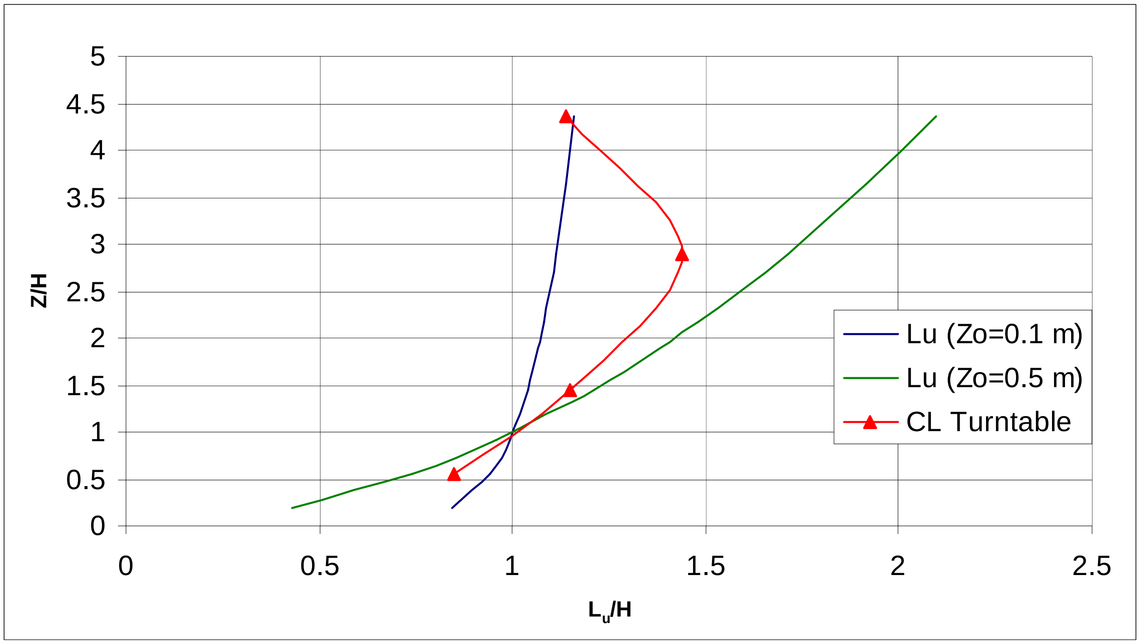

Figure 6.3-Targeted vs. Actual Length Scale

Table 6.4-Alpha and Roughness Coefficient Comparison

Source	**α**	**z_o (m)**
ASCE 7-02	4	0.3
LSU	4.07	0.24

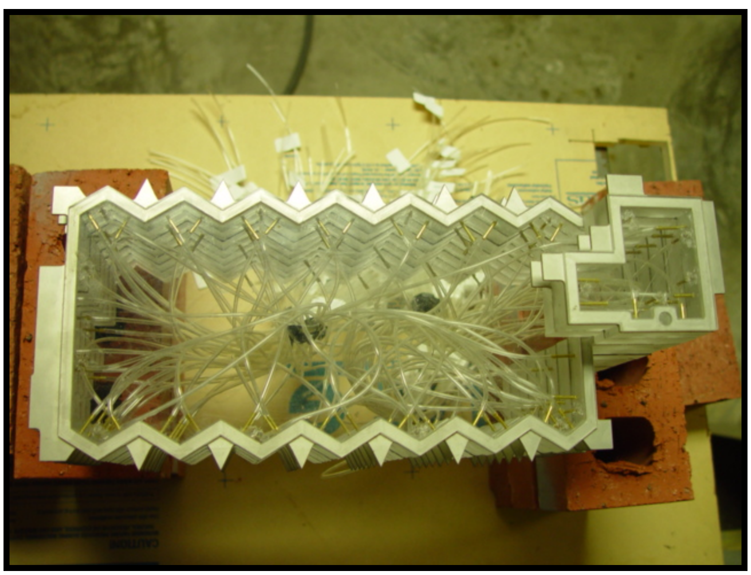

Figure 6.4-1:200 South Wing Model with Pressure Taps

cut in the shape of the building and matched the scaled thickness of the 11' and 13' tall floors (minus the thickness of the window shades). The acrylic and stainless steel sections were then sealed together with silicone. Like the Texas Tech experiment, taps were drilled and then counter drilled on the inside allowing the tap to have an uniform interior diameter. Figure 6.4 is a top view picture of the 1:200 model of the South Wing with pressure taps.

6.4.1 Pressure Test

In order to test the 156 pressure taps for leaks, the model was sealed to the wind tunnel and covered with a plastic bucket. The plastic bucket and any loose bundles were sealed and the plastic bucket pressurized. With a constant pressure on the model, tests using the Scanivalve system were compared to pressure readings in the bucket determined with a monometer. Throughout all the tests, the plastic box and all the taps held a constant pressure. Figure 6.5 is a picture of the model prior to being tested for leaks with the system described.

Figure 6.5-Leak Check

6.4.2 Tap Location

Ideally, every window and the majority of the roof would have pressure taps. The model's interior space and twelve sixteen channel couples limited the number of pressure taps to 156. Knowing that the roof and corners and upper floors would have the highest pressures, majority of the taps were placed in those areas. Wall taps were located between the window shades, where existing windows are, and roof taps were centered between the main pan and joist system. Figures 6.6-6.19 are the names and locations of the pressure taps for the model. The first number in the tap name indicates the floor; second letter indicates the side; and third number indicating that walls numerical value with everything ascending counterclockwise.

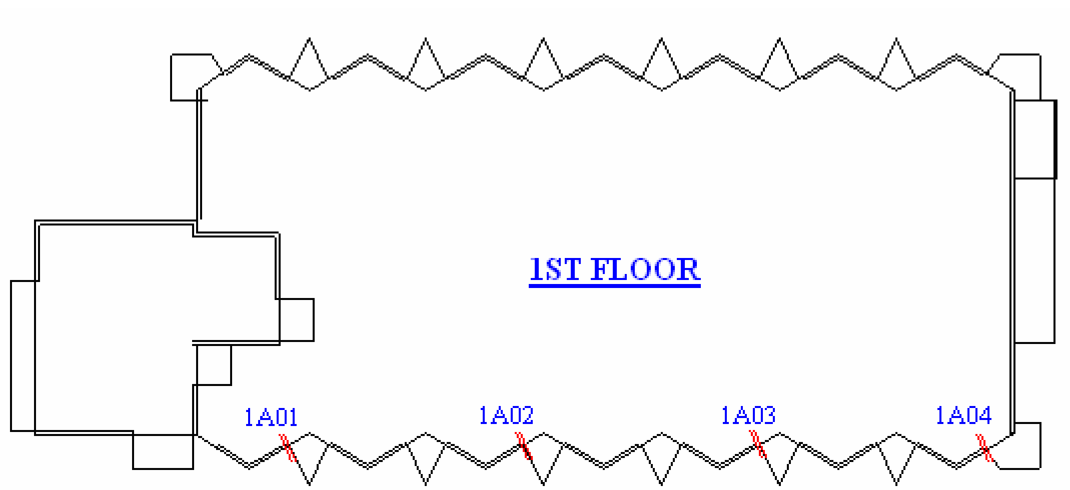

Figure 6.6-1st Floor Tap Locations

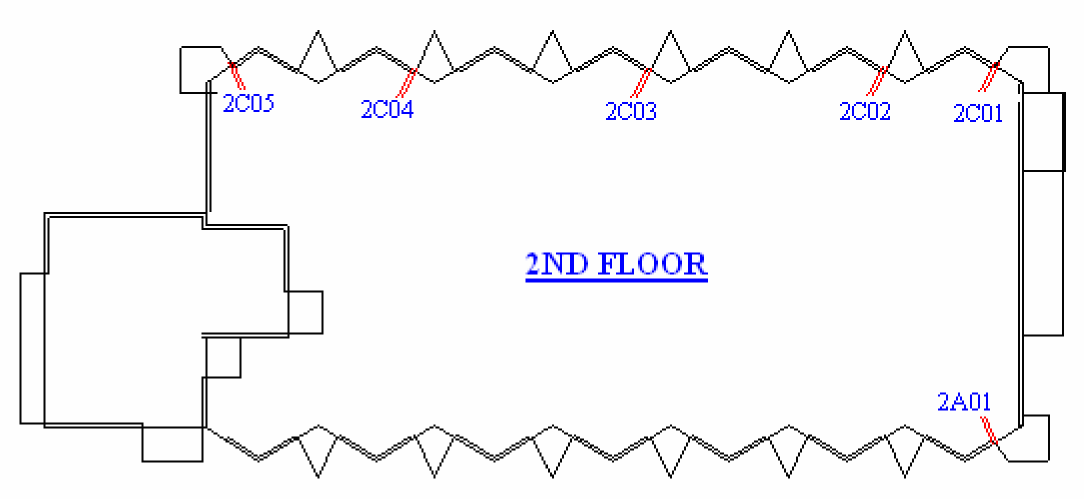

Figure 6.7-2nd Floor Tap Locations

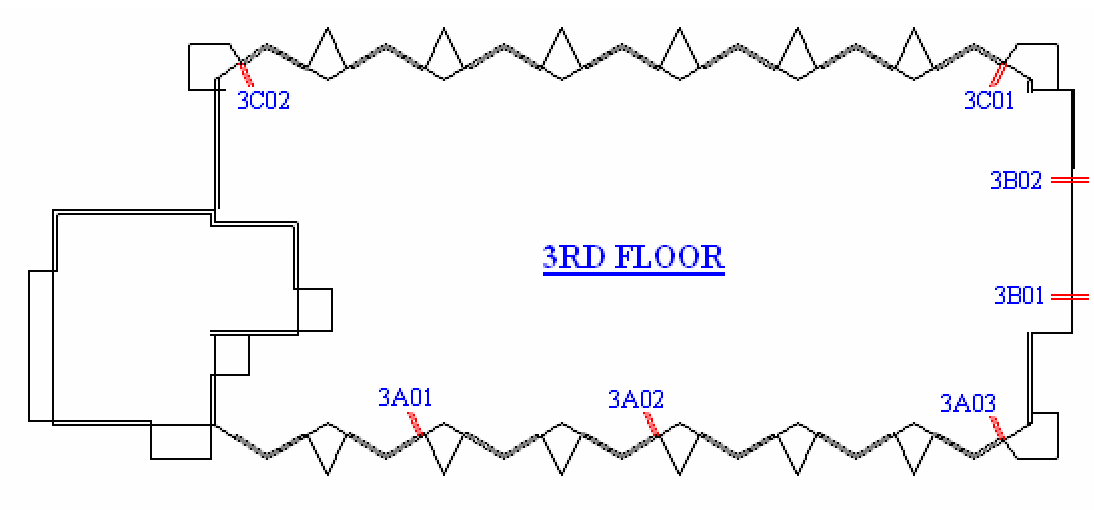

Figure 6.8-3rd Floor Tap Locations

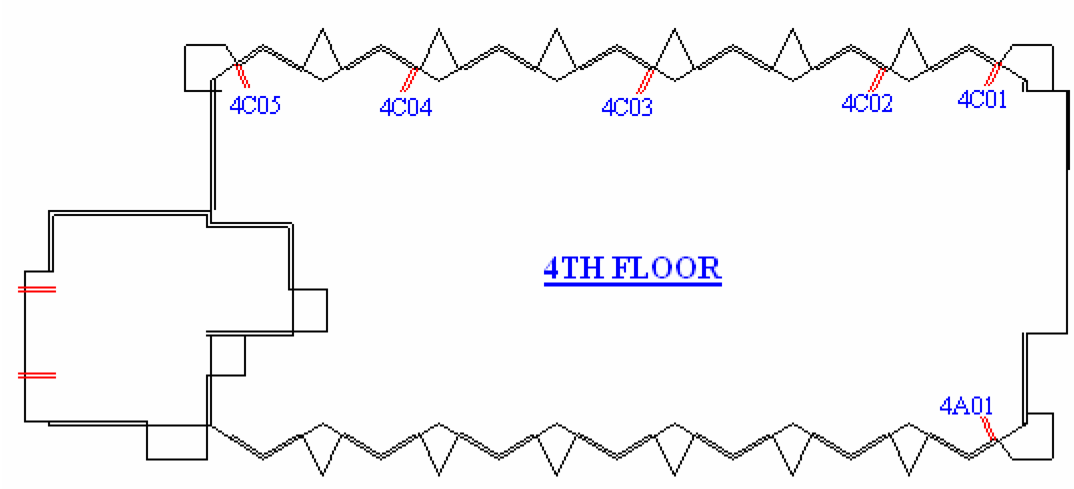

Figure 6.9-4th Floor Tap Locations

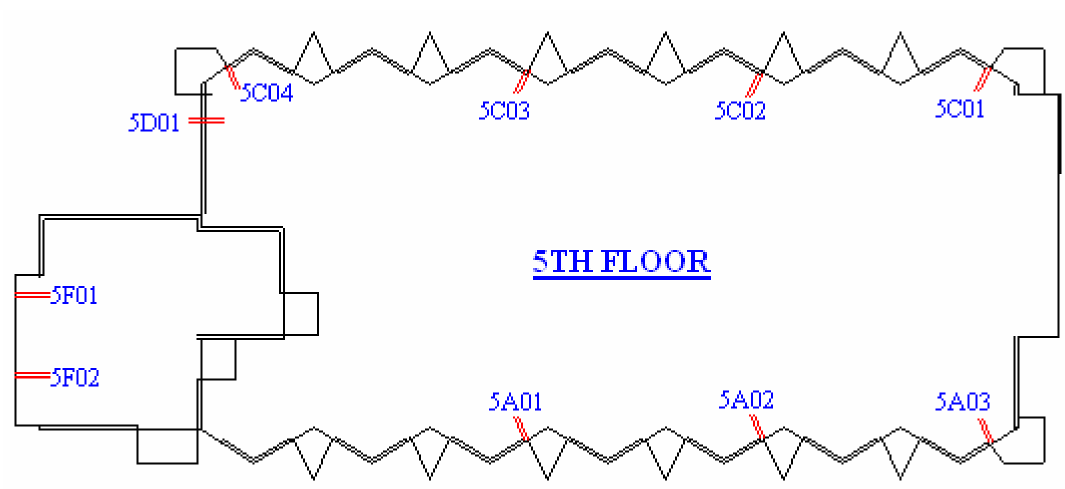

Figure 6.10-5th Floor Tap Locations

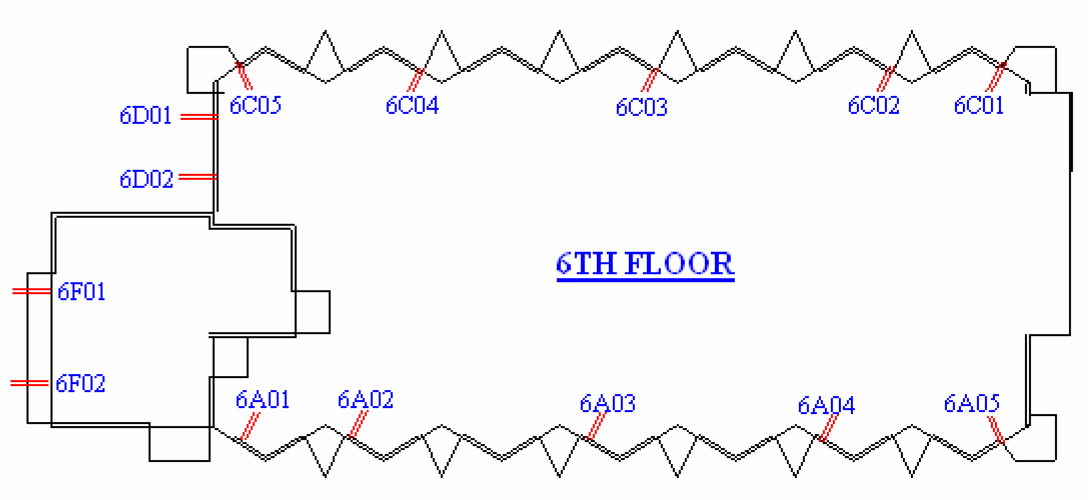

Figure 6.11-6th Floor tap Locations

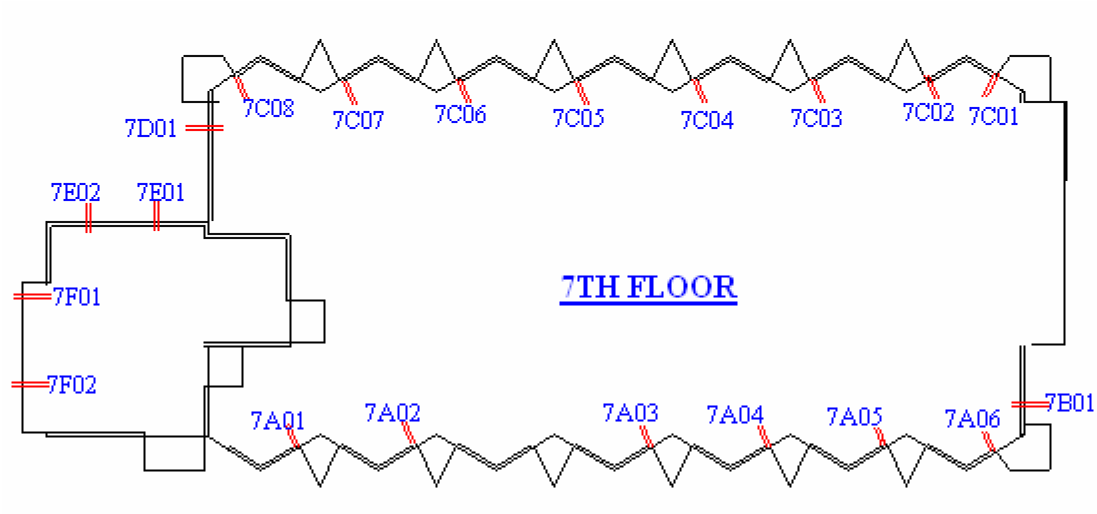

Figure 6.12-7th Floor Tap Locations

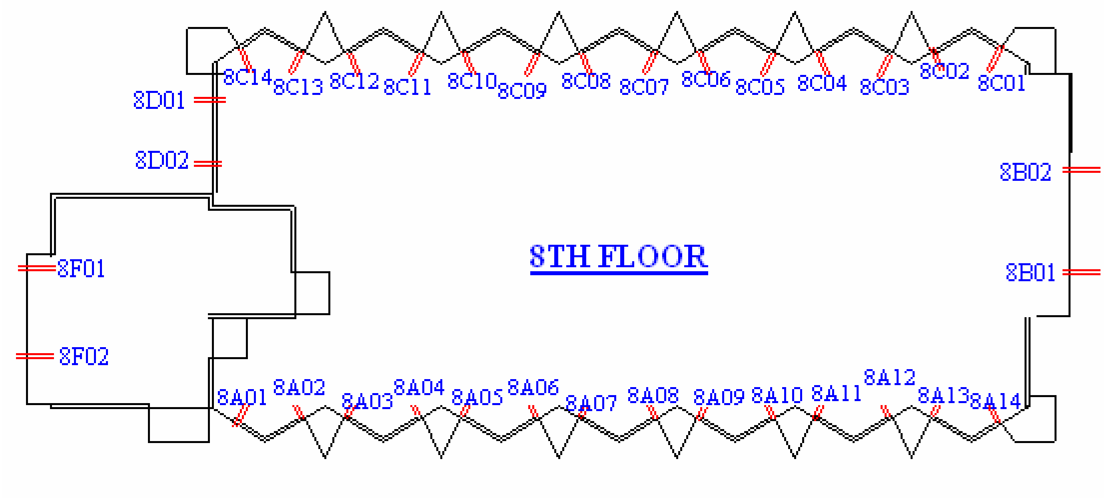

Figure 6.13-8th Floor Tap Locations

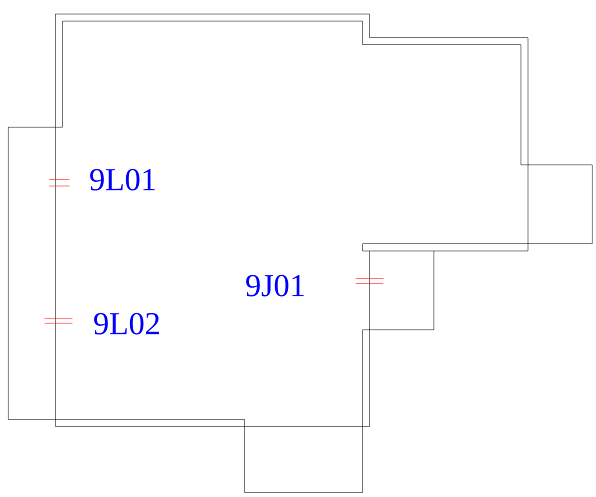

Figure 6.14-9th Floor Tap Locations

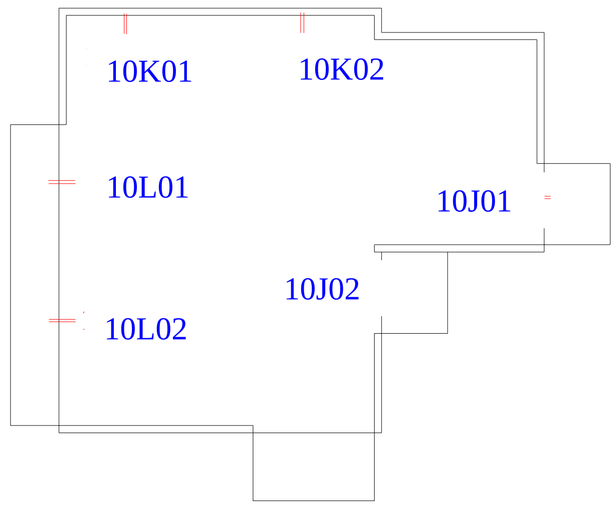

Figure 6.15-10th Floor Tap Locations

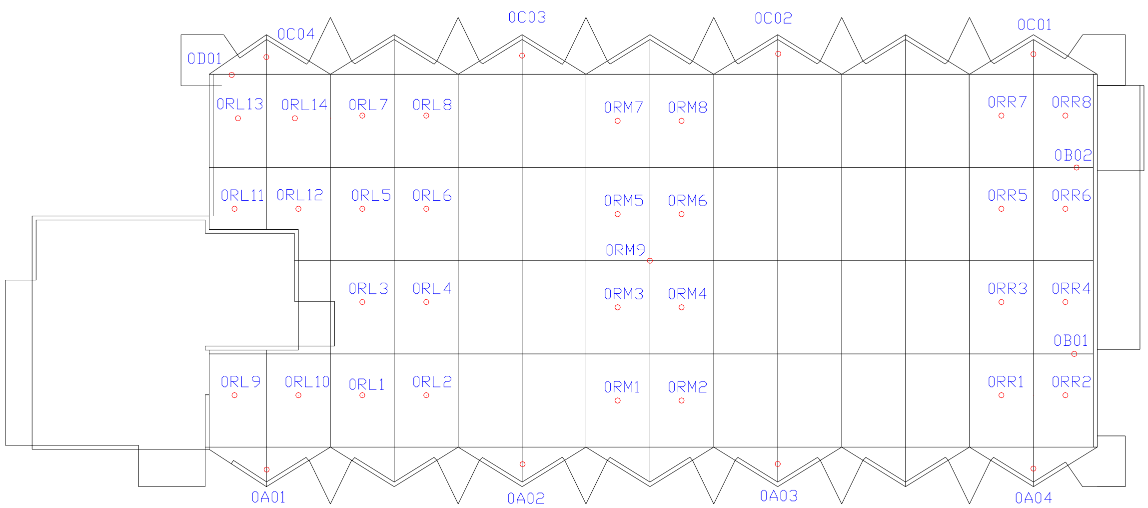

Figure 6.16-Roof Tap Locations

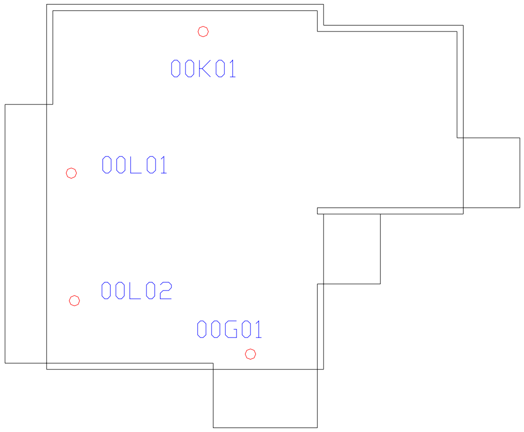

Figure 6.17-Tower Roof Taps

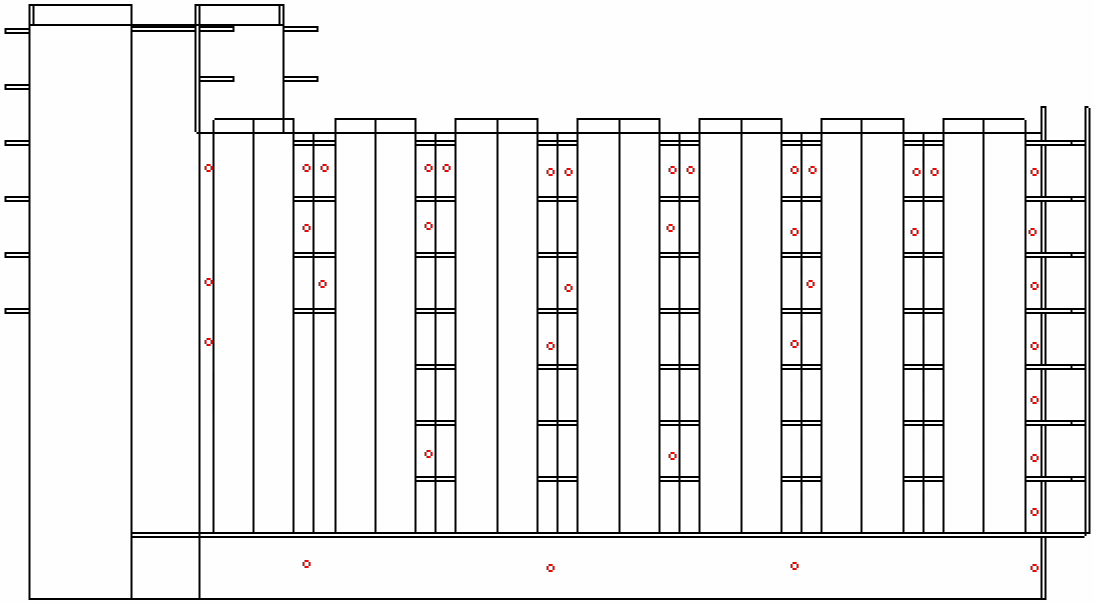

Figure 6.18-Front Side Tap Locations

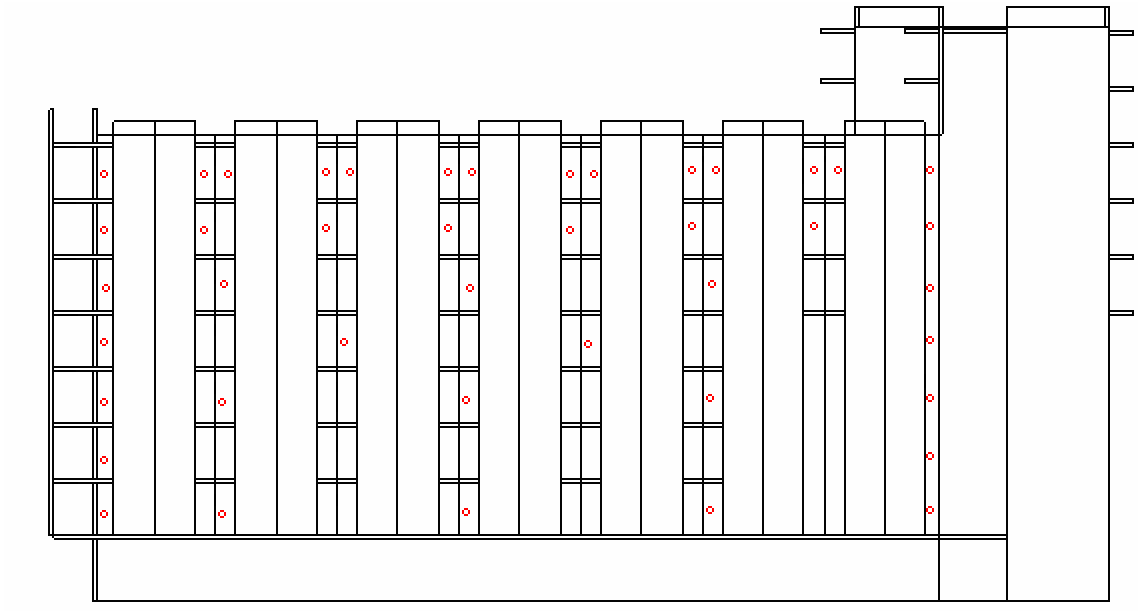

Figure 6.19-Back Side Tap Locations

6.5 Wind Tunnel Tests

6.5.1 Wind Tunnel Test Duration

Following the Texas Tech experiment, equation 6.1 was used to determine the scaled testing time, which equates to an hour in full-scale conditions. The hourly wind speed was then broken into four fifteen-minute segments to determine the peaks and valleys. Using Equation 6.1 resulted in a scaled testing time of 132 seconds. The 132 seconds was then divided into four intervals of 33 seconds with the peak pressure coefficients evaluated for each segments and averaged to determine the positive and negative peaks. The mean pressure for a tap was an average of the entire run, 132 seconds.

$$\frac{T_m}{T_p} = \frac{1/200}{U_m/U_p} \qquad [6.1]$$

T_m = Time interval for model
T_p = Time interval for actual hospital
U_m = Velocity at 6'' in wind tunnel (mean roof height)
U_p = Exposure B Velocity at 92 ft using ASCE 7

Using T_m = 33 seconds, $U_{6''}$ = 9.94 m/s, $U_{100'}$ = 73.7 m/s this yields a T_p of 15 minutes.

6.5.2 Tests

After the wind tunnel and instrumentation was calibrated, tests were conducted on the model every 15° for 360°. Figure 6.20 illustrates the orientation of testing on the turntable. Both of the Scanivalve systems were attached to 12 tap bundle and the wind tunnel was left running at a constant velocity while all angles were tested. Throughout each test the data was processed and evaluated to determine if any tubing came loose or disconnected. After testing all 12 bundles the data was corrected for the digital, static, and dynamic corrections and then converted to pressure coefficient by dividing that taps pressure by the reference pressure. The peak pressures were then determined by taking the averaging the four peak pressures over the time interval discussed in section 6.5.1. The mean pressure was calculated over the entire time history, correlating to a mean hourly wind speed.

6.5.3 South Wing Results

After the pressures were digitally corrected and converted into pressure coefficients, the positive and negative peaks, mean pressures, and root mean square (RMS) were plotted based on the angle of attack. Positive and negative peaks and mean pressures were compared amongst each other and adjacent taps to give an understanding of the flow conditions as well as to reveal any irregularities. Taps that had high peak and mean pressures compared to ASCE 7 method two were investigated to ensure the results were realistic. Figure 6.21 and 6.22 are charts for eighth floor corner tap 8C02 and roof corner tap 0RR2. Although, tap 8C02 has a high positive peak the mean is close to unity as expected. Roof tap 0RR2 has a low negative peak pressure of -8 around 45°-60°, which is the windward front corner. Comparing to method two, the roof taps should have a high negative peak and a negative mean, which this roof tap does have. For a complete list of the charts and pressure results for each tap refer to Appendix E.

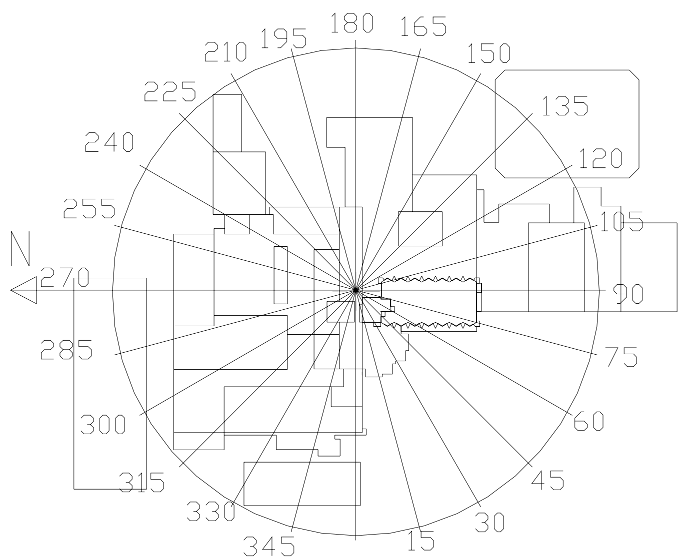

Figure 6.20-WJMC Testing Orientation

Figures 6.23-6.29 are positive and negative peak pressure coefficients for the wall and roof pressure taps. For the wall taps the first floor taps have lower pressure coefficients and progressively get larger as you move closer to the corner and higher. Positive peak roof pressure, figure 6.28, are low near on the south side but high on the north side. These higher positive peak pressures can be attributed to the mechanical tower extending two stories above the roof creating a wall. The negative peak roof pressures, figure 6.29, values are lowest at the southwest corner which faces a parking lot and open field. The southeast corner also has low peak pressures but not as high due to surrounding buildings.

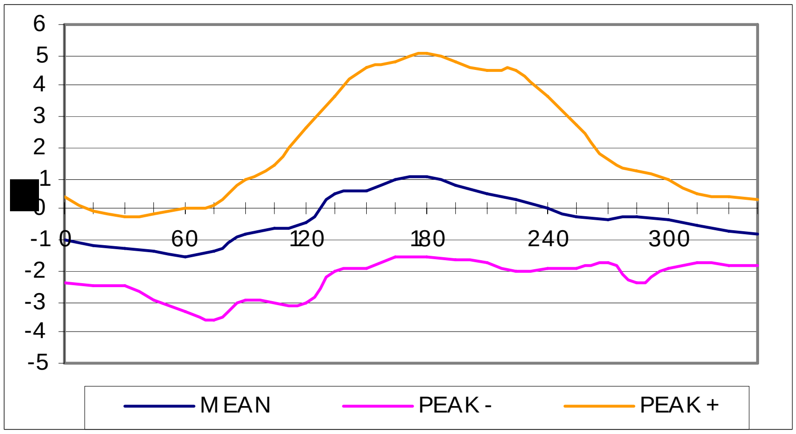

Figure 6.21a-Tap 8C02 Mean, Peak, Valley Pressure Coefficients vs. Angle

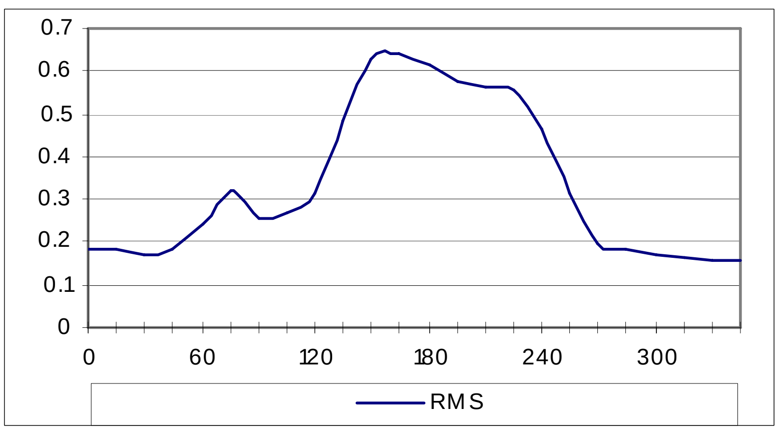

Figure 6.21b-Tap 8C02 RMS

6.5.4 Validation of WJMC Wind Tunnel Results

Results for the West Jefferson Medical center tests were also sent to Cochran of CPP for review. As with the Texas Tech experiments, the low longitudinal length scale might have increased the roof pressures. With the pressure results not being far from what he expected and being on the conservative side he felt they were satisfactory.

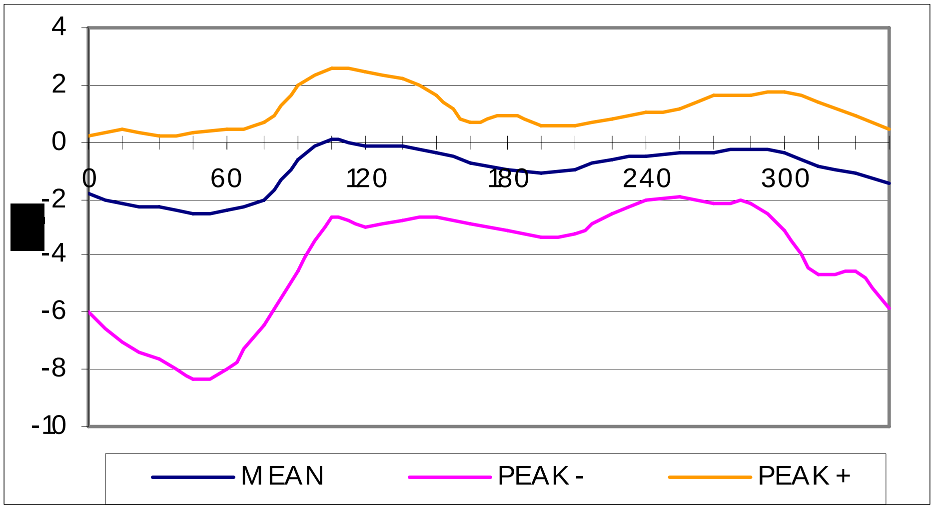

Figure 6.22a-Tap 0RR2 Mean, Peak, Valley Pressure Coefficients

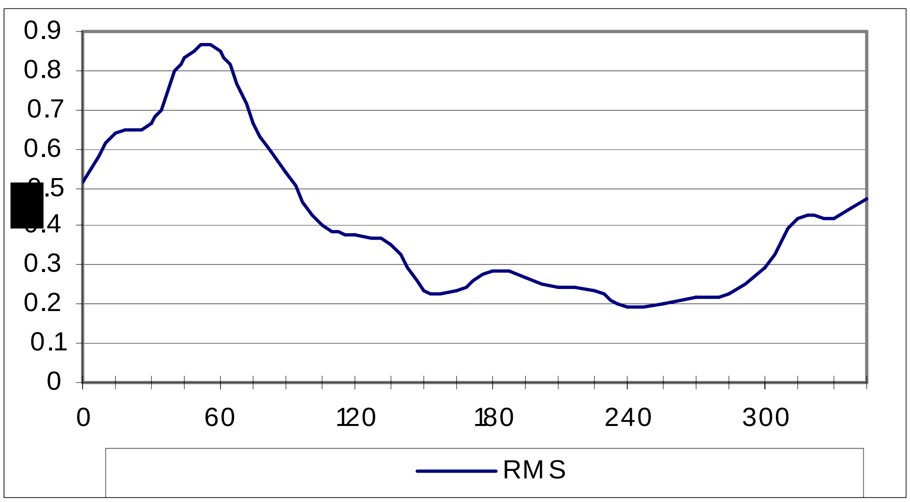

Figure 6.22b-Tap 0RR2 RMS

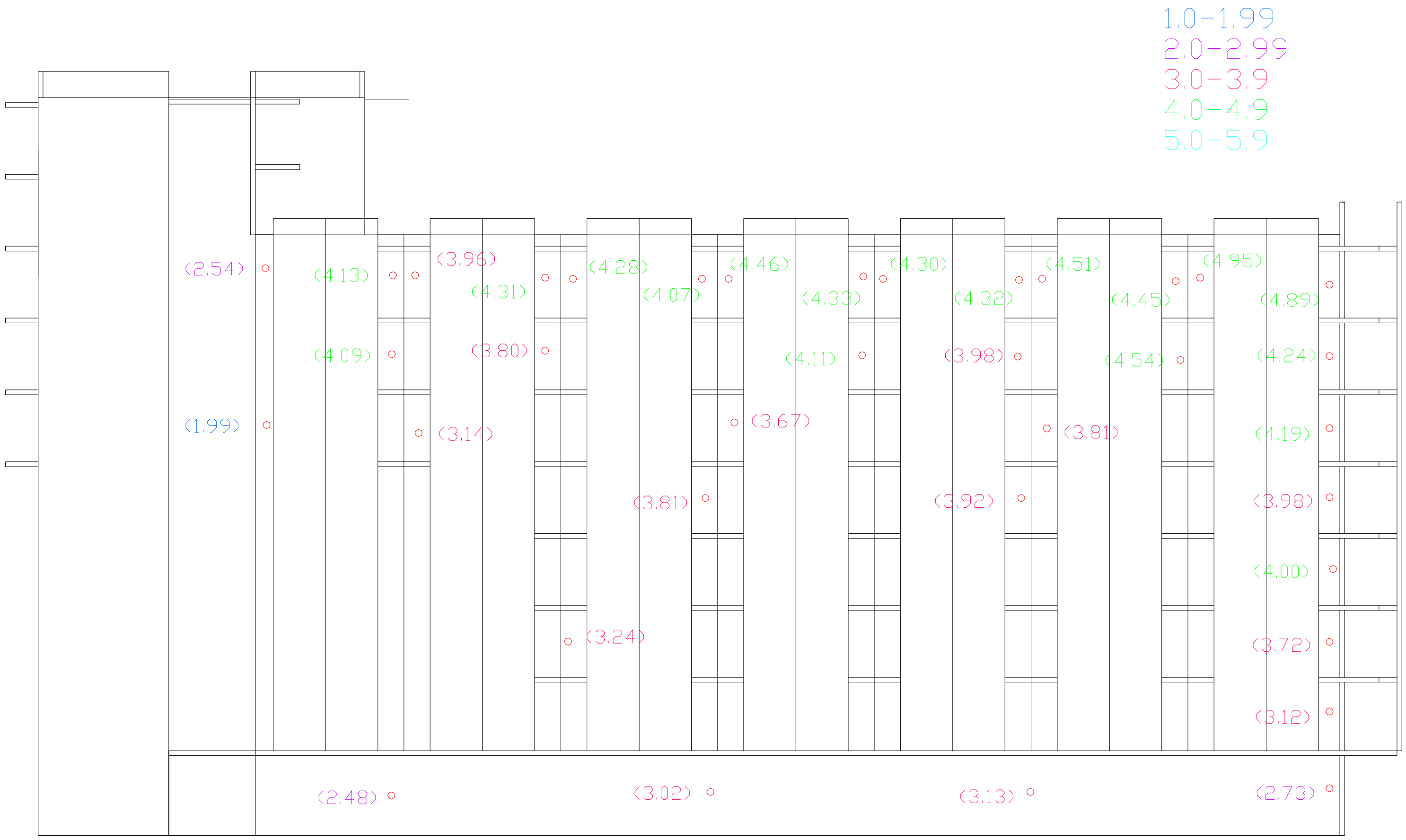

Figure 6.23-Front Positive Peak Pressure Coefficients

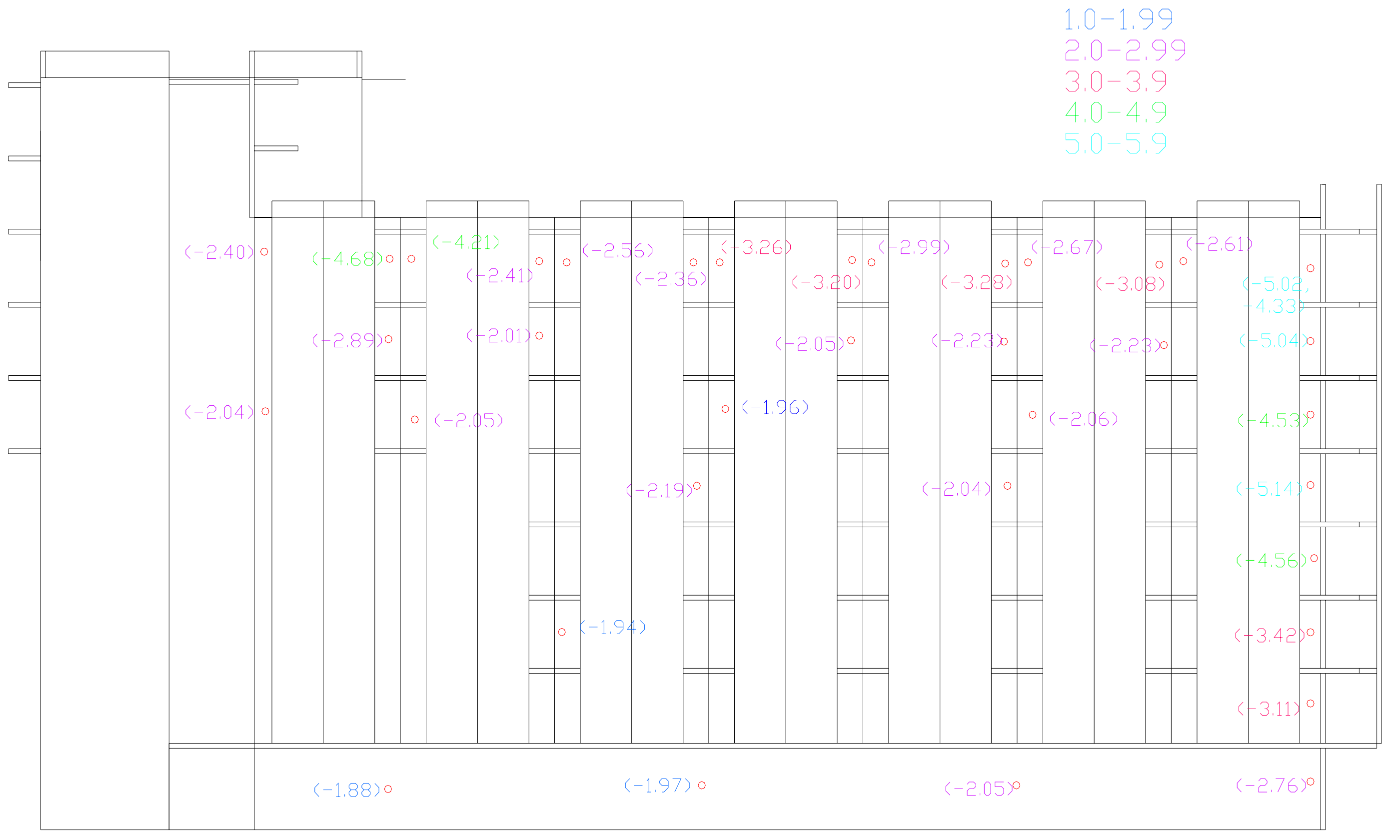

Figure 6.24-Front Negative Peak Pressure Coefficient

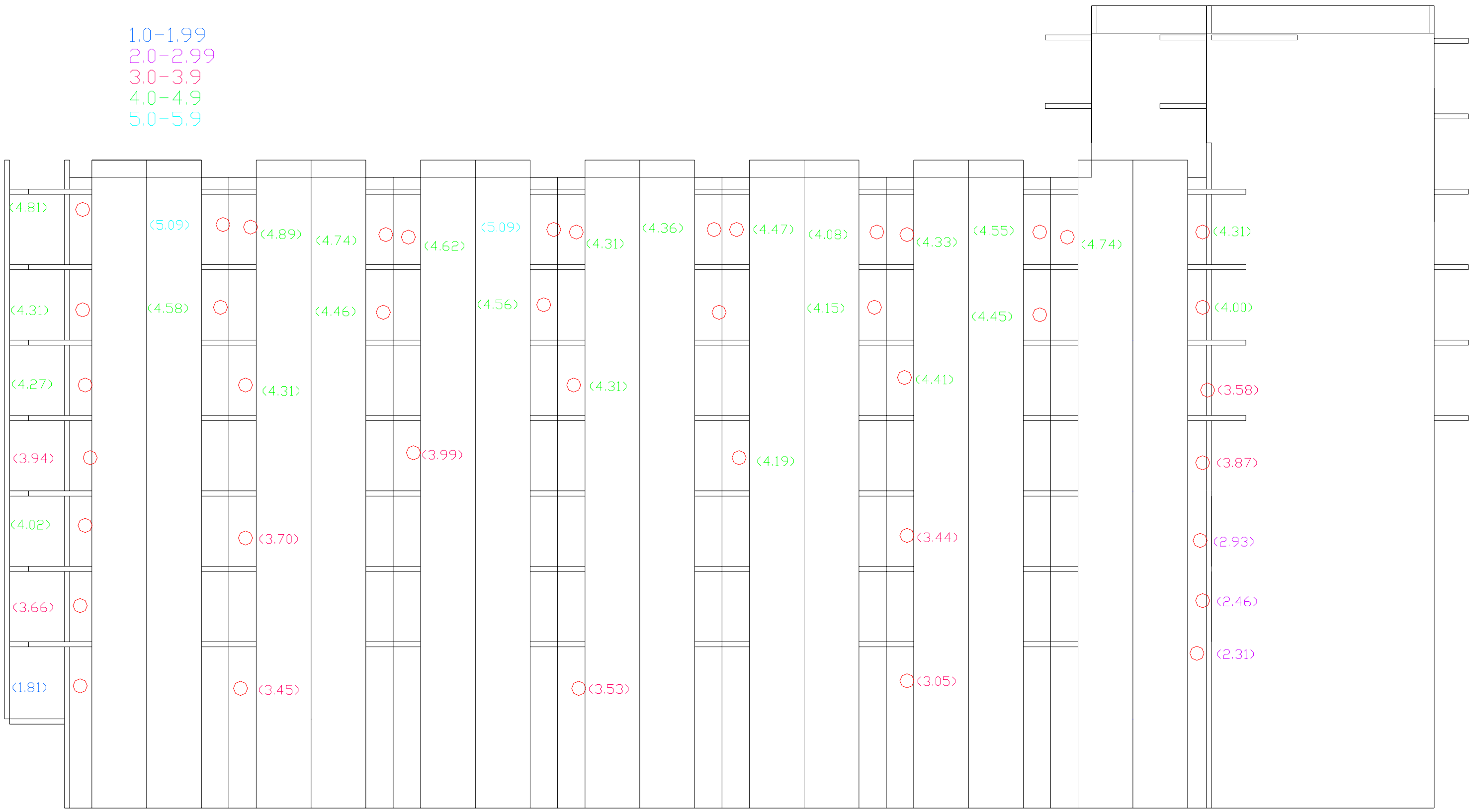

Figure 6.25-Bask Side Positive Peak Pressure Coefficients

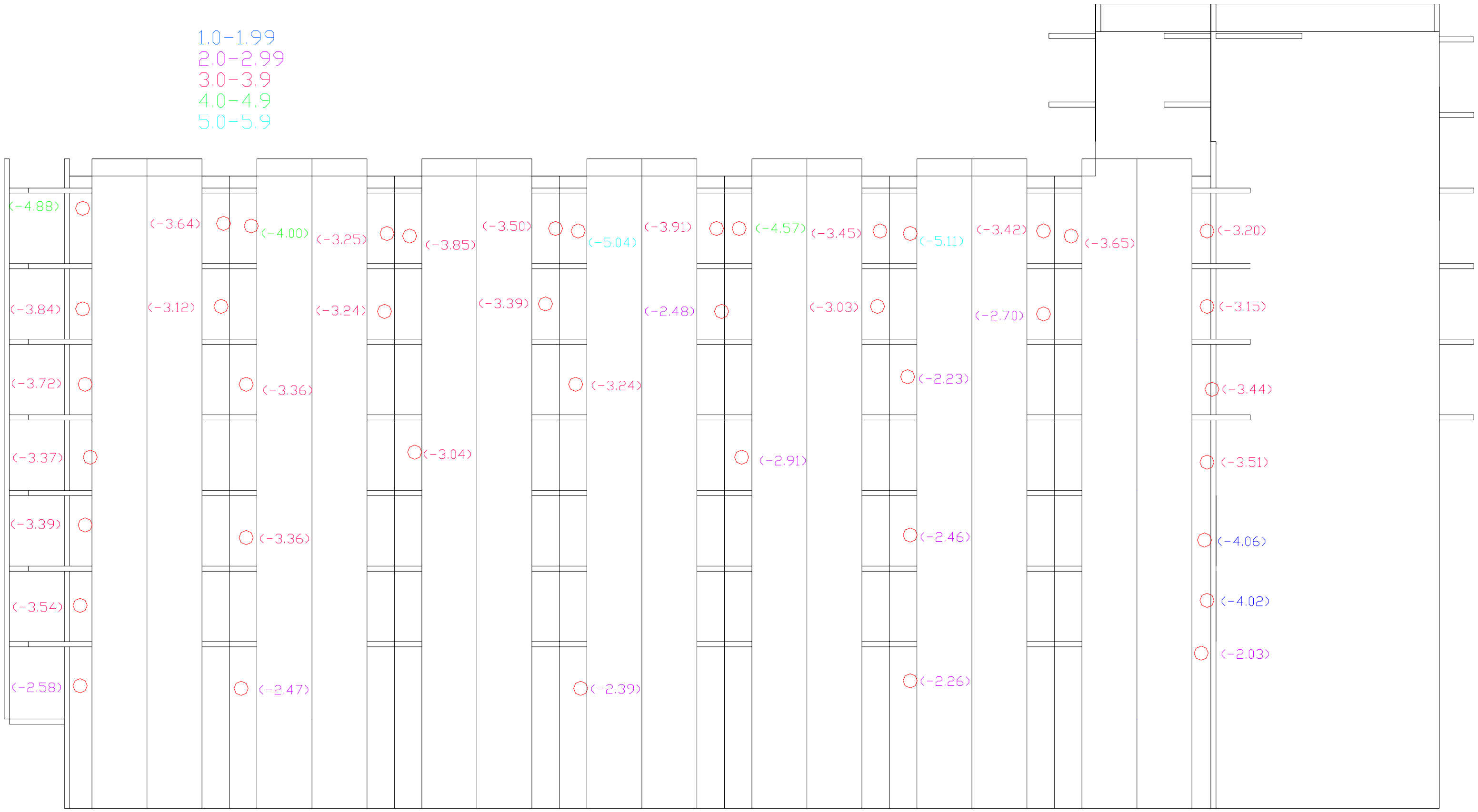

Figure 6.26-Back Side Negative Peak Pressure Coefficients

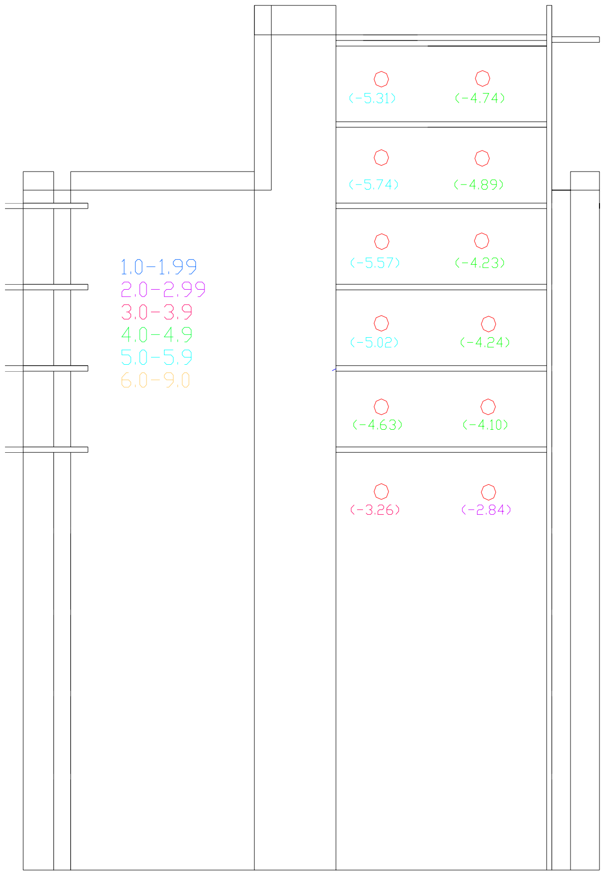

Figure 6.27-North Wall Negative Peak Pressure Coefficients

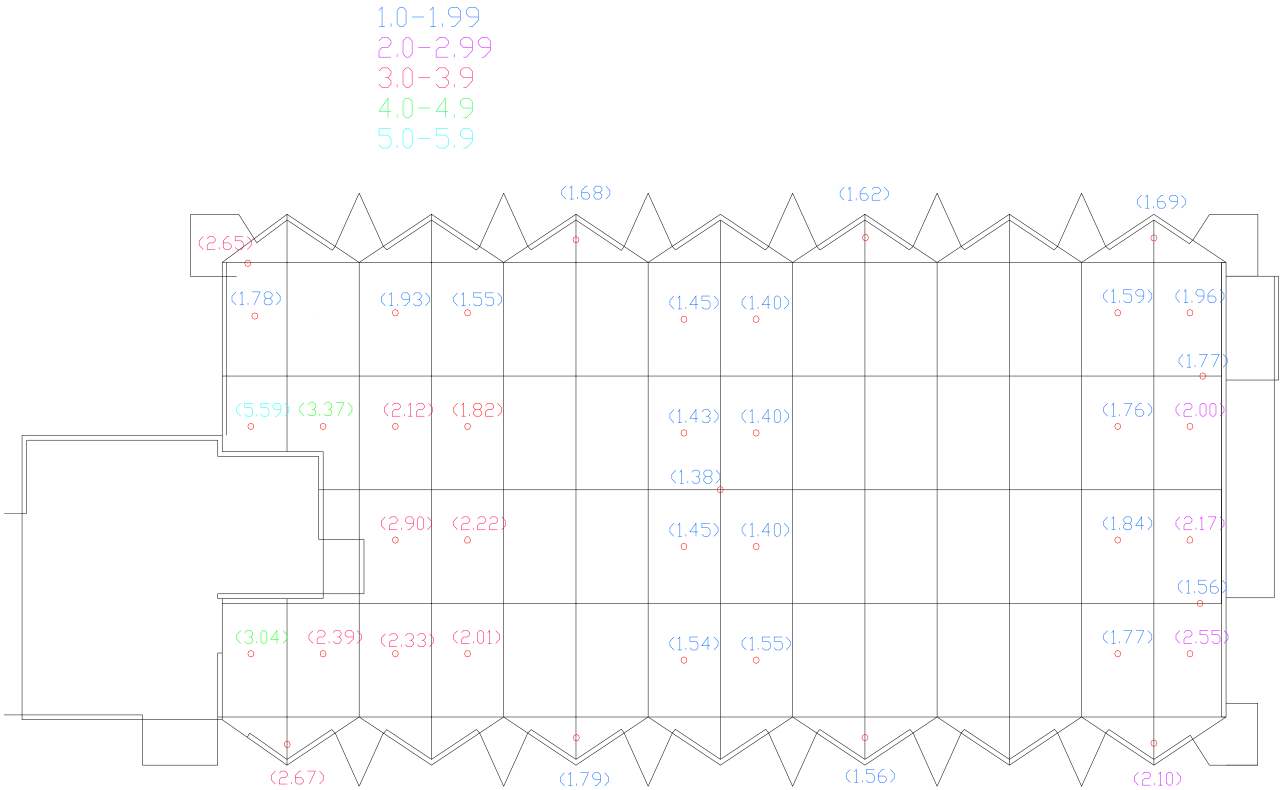

Figure 6.28-Roof Positive Peak Pressure Coefficients

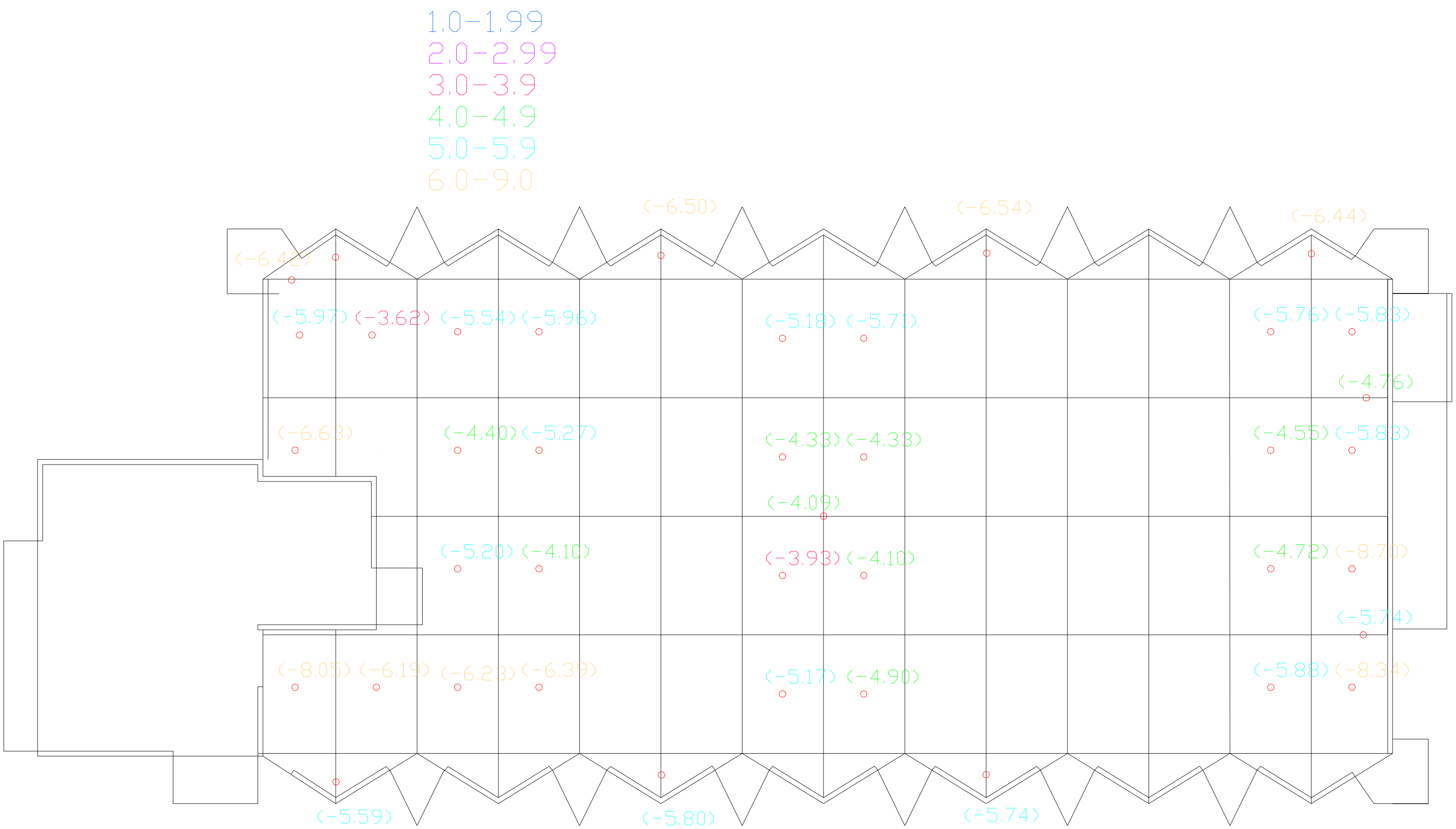

Figure 6.29-Roof Negative Peak Pressure Coefficients

CHAPTER 7: ANALYSIS

7.1 Introduction

Using the adopted method in Chapter 3 and wind tunnel results in Chapter 5, the West Jefferson Medical Center was evaluated to determine its capabilities as a hurricane shelter for any possible hurricane scenario. To accomplish this, an in depth understanding of the hospitals current integrity and strength was performed, flood levels determined, and wind tunnel results for the main wind force resisting system and components and cladding also determined.

7.2 Wind Analysis

In order to apply the hurricane wind speeds to the wind tunnel results, table 3.4 was modified for proper exposure (exposure B), the mean roof height of the South Wing (92'), and a fifteen-minute mean wind speed. Vickery noted when using table 3.4, that Krayer-Marshall (ASCE, 1996) curve was used to determine wind speeds for hurricane prone regions, therefore, Krayer-Marshall curve was also used to convert table 3.4 three second gust at land fall to a fifteen-minute wind speed (Vickery et al, 2000). The difference in heights between the mean wind speed and roof mean height must also be considered. Saffir-Simpson wind speeds are referenced at 33 ft from the ground and wind tunnel data is referenced at the roof mean height, 92 ft. Equation 7.1 was used in conjunction with ASCE 7 and above factors to create table 7.1 (ASCE, 2002).

As discussed in section 3.7.3, to determine the upper bound of a category five storm Hurricane Camille's wind speeds were used and interpolated with Vickery's table to obtain a wind speed at landfall.

$$U_{92'} = U_{33'}\left(\frac{1.05}{1.67}\right)\left(\frac{900}{33}\right)^{1/6.5}\left(\frac{92}{1200}\right)^{1/4.0} \qquad [7.1]$$

When computing each taps hurricane pressures using equations 2.2 and 2.3 the gust effect factor, G, velocity pressure, K_z, and topographic factor, K_{zt}, are already included in the wind tunnel flow and must be set equal to one, resulting in equation 7.2 for the velocity pressure and equation 7.3 for pressures. According to Easley (2003) and table 3.7, the directionality factor, K_d, should be 0.95, however, by testing the model at different directions the directionality factor was included in the wind tunnel tests and was set to one.

Table 7.1-WJMC Adjusted Wind Velocities

Saffir-Simpson Category	Saffir-Simpson Scale (mph)	Max Gust Speed Over Land (mph) z_o=0.1 ft (.03m)	15 min mean velocity 92 ft above land (mph) z_o=0.98ft
1	74-94	82-108	46-60
2	94-110	108-130	60-72
3	110-130	130-156	72-86
4	130-155	156-191	86-105
5	>155	238	131

$$q = .00256V^2 \quad \text{(psf)} \qquad [7.2]$$

$$p = q\left(C_p - GC_{pi}\right) \quad \text{(psf)} \qquad [7.3]$$

Assuming failure is once the envelope has been breached, the structure was treated as partially enclosed, GC_{pi} equal to +/- 0.55, leaving C_p and velocities in table 7.1 as the variables.

7.2.1 Decay in Wind Speed over Land

To determine the expected wind speeds at the site, the 15-minute wind speeds at 92 ft in table 7.1 were used in conjunction with figure 3.6, Ho's, (1987) wind speed adjustment factor. Reviewing the flood analysis in section 5.6 and table 5.1, the distance from the coast varies from 60 – 20 miles for a Category 1, 30 – 10 miles for a Category 2, and 0 miles for a Category 3-5. Meaning the reductions are 0.86 – 0.95 for a Category 1, 0.92 – 0.97 for a Category 2, and zero for a Category 3 –5.

7.3 Structural Analysis

7.3.1 Overview

Being designed as heavy reinforced concrete structure with shear walls table 3.1 indicates this type of construction is inclined to perform well under high winds. It was felt that the overall structural integrity of the hospital is in good shape. However, reviewing the structural plans it appeared the roof was designed the same as the lower floors, which were not designed for an uplift pressures.

As the uniform pressure is applied to the 3″ thick slab, the load will distribute to the 6″ deep pans, then to the 16″ x 16″ girders, next to the columns, and finally to the ground. Eventually as the applied load become greater, the concrete will begin to crack. Once the concrete cracks, reinforcing steel will carry the load. With a yield strength of 60,000 psi, the reinforcing is more than adequate to handle roof uplift pressures. However, with the roof designed for live load, the location of the reinforcing steel was checked. The uplift pressures will place the bottom section of the girder in compression and top in tension, meaning the top must have reinforcement. Without top reinforcing, once the moment applied becomes greater than the cracking moment for a section the member will fail causing that section of the roof to collapse.

Reviewing the structural plans, the 16″ x 16 ″ girders have continuous bottom reinforcing but there is a 7′ gap in the top reinforcing at center span, which is the same as no top reinforcing.

7.3.2 Correlation

Ideally, all the pressure taps would have been tested simultaneously allowing for all the taps to easily correlated. However, with almost forty roof pressure taps and thirteen taps to a bundle, not all the taps could be simultaneously tested. Roof pressure taps were bundled based on sections; left taps 0RL1-8, middle taps 0RM1-8, and right taps 0RR1-0RR8. Bundling sections of the roof, each section pressure taps could be applied concurrently to the structural model to determine the structures response to the applied winds.

7.3.3 Pressure Analysis

Reviewing figure 6.29, the front right corner, taps 0RR1-8, have the heights uplift pressures and will be used for structural analysis of the roof. Being a very structurally redundant system, when loads are applied to one side of the roof it will have a minimal affect on the other side. Therefore, only the right side was investigated for failure and assumed once the corner failed the top floor would no longer be used.

7.3.4 Structural Analysis

7.3.4.1 Cracking Moment

As discussed in section 6.2.4.2 the 16" x 16" joist will fail once the applied uplift pressures are greater than the cracking moment. For completeness, the 6" deep pans cracking moment will also be checked against the applied moment. Equation 7.4 is the equation for computing the cracking moment for a beam (ACI, 2002).

$$M_{cr} = \frac{7.5\sqrt{f_c'}(I_g)}{y} \qquad [7.4]$$

M_{cr} = Cracking Moment (in-lbs)
F_c' = concrete compressive strength (psi)
I_g = Moment of Inertia (in^4)
y = distance from neutral axis to the extreme fiber in tension (in)

Reviewing equation 7.4, the cracking moment depends on compressive strength, geometry of the beam, and location of the neutral axis from the side in tension. Over time the geometry of a structure will not change but the compressive strength can increase. If concrete has been exposed to high humidity the compressive strength will increase by 30%-40% over a 20-year period. However, when not exposed to high humidity, the compressive strength only has a minor increase (Woods, 1991). With the girders being inside and air conditioned, the design compressive strength was used in determining the cracking moment.

When the applied moment lifts the 16" girders and 6" deep pans the 3" slab will provide some strength. When determining the neutral axis the 3" slab will be included in the depth for both the girder and pans, however the pans will also have an effective flange width, further increasing the neutral axis. Figures 7.1 and 7.2 are the cracking moment calculations for the 16" girder and 6" pan based on ACI 318 (ACI, 2002).

7.3.4.2 Visual Analysis

To determine how the girders will react under the applied load a finite element program, Visual Analysis 3.1 was used. Being only interested in the front right corner of the roof, a one-story model with 3-12' x 4-17' bays was developed. Although only a portion of the roof was modeled, the South Wing was designed as an determinate system and the affects from other bays would be minor. Instead of applying the pressure results to the model, a uniform unit load was individually placed on taps 0RR1-0RR8 and the influence lines from each unit load determined for the center of the 16" girder between pressure taps 0RR1 and 0RR2, taps with the heights pressure, and the 6" deep pans associated with tap 0RR2, for tap locations refer to figure 6.16. The shear, reaction forces, and moment forces based on each taps unit load were calculated for the girder and pans in study. Figure 7.3 is a unit load applied to tap 0RR2.

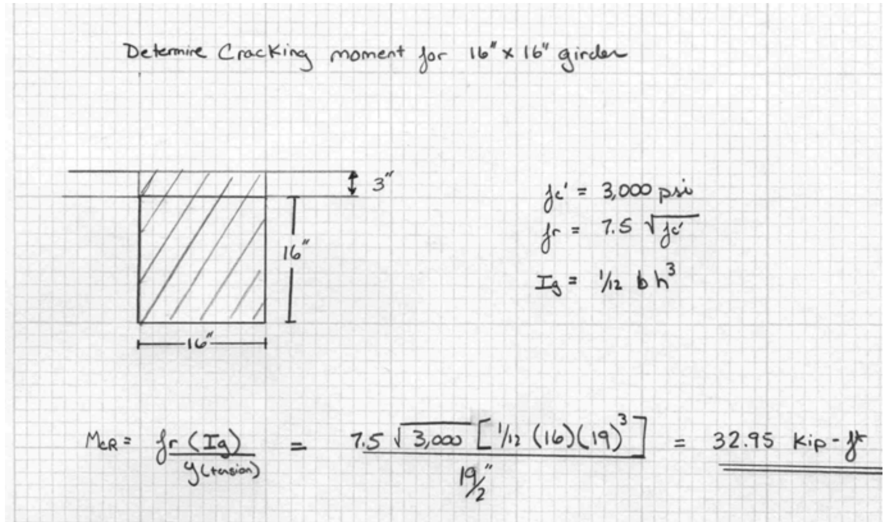

Figure 7.1-16" x 19" Beam Cracking Moment

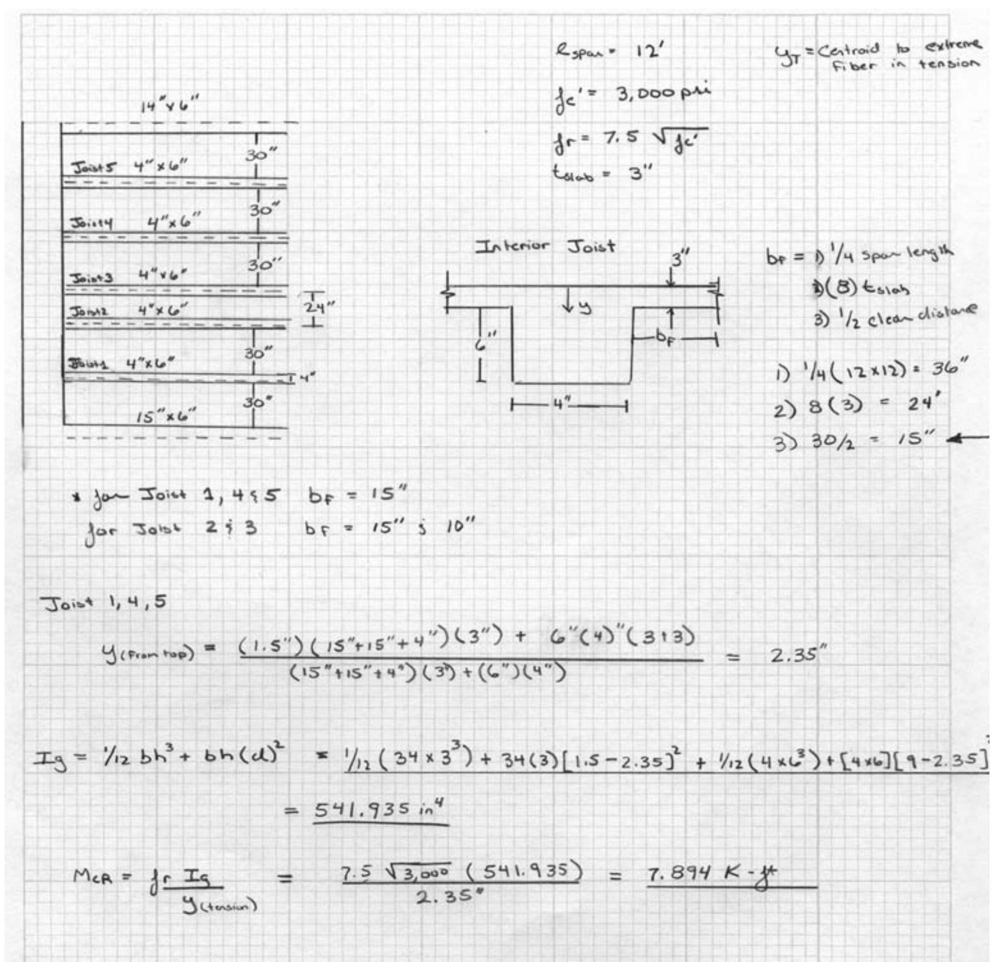

Figure 7.2-6" Deep Pans Cracking Moment

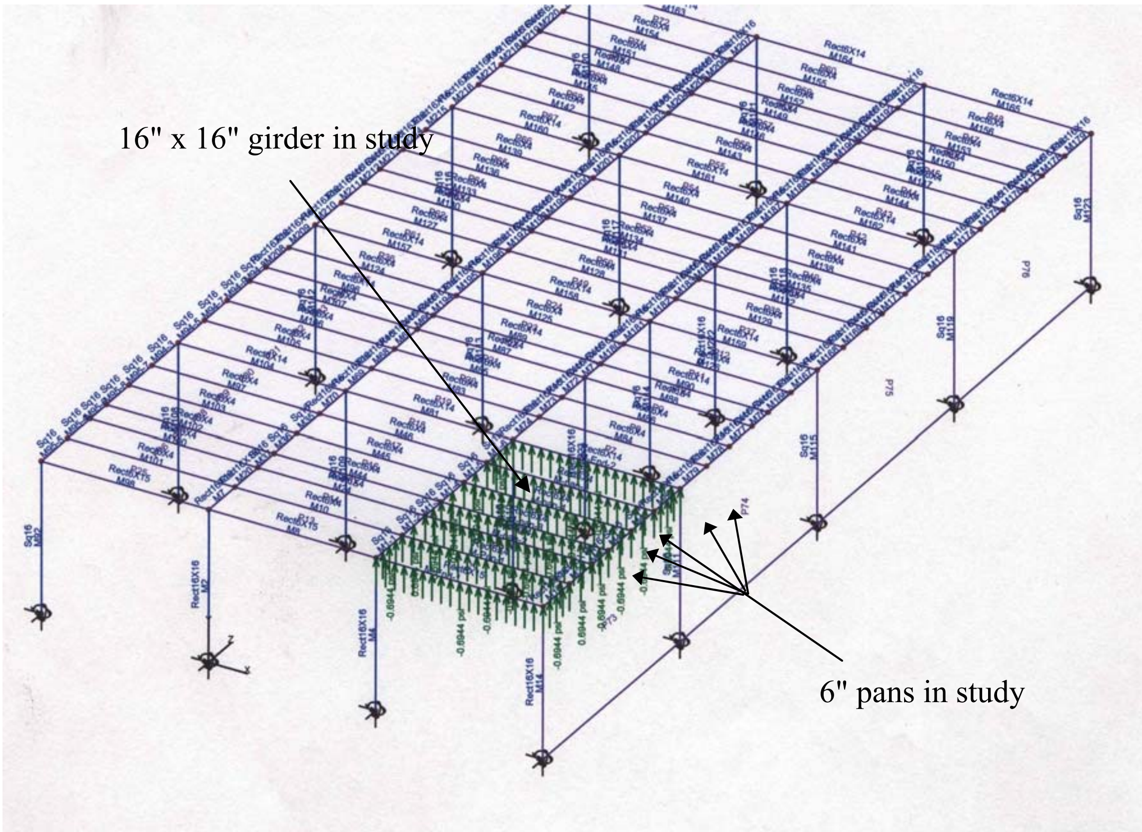

Figure 7.3-Structural Analysis with a Unit Load Applied to Tap 0RR2

7.3.4.3 Influence Lines Results

Recording the moments on the 16" girder and the 6" deep pan from each taps unit load, the results were then divided by the unit load and values recorded in table 7.1. By developing influence lines, the factors in table 7.2 were applied to the time histories for taps 0RR1-0RR8 for the worst-case directions. Figure 7.4 is a moment time history compared to the cracking moment for the 16" girder at 45° subjected to Category 4 hurricane pressures; refer to figure 6.20 for testing orientation. Once the applied moment exceeds the cracking moment anytime in the moment time history, the girder was considered to have failed. Although, the moment time history might have surpassed the cracking moment only once for a short period of time it was still considered failure.

Table 7.2-Influence Lines Results from Structural Analysis

16"x16" Girder Influence Line

$Mz_{97''}$ (lb-in)/(psf)

0RR1	*0RR2*	*0RR3*	*0RR4*	*0RR5*	*0RR6*	*0RR7*	*0RR8*
-1164.62	-1122.19	62.41	25.7354	-0.771	-0.531	2.3666	0.8458

6" deep pans

$Mz_{midspan''}$ (lb-in)/(psf)

0RR1	*0RR2*	*0RR3*	*0RR4*	*0RR5*	*0RR6*	*0RR7*	*0RR8*
7.64872	-215.30	0.58	-2.6758	0.029	-0.234	0.00	0.00

Reviewing table 7.2 the 16" girder applied moment surpasses the cracking moment at 45° at 131 mph. Although this only happens once at a specific angle for a strong category five wind speed, it is not recommended that the top floor be used during a category five storm from any direction.

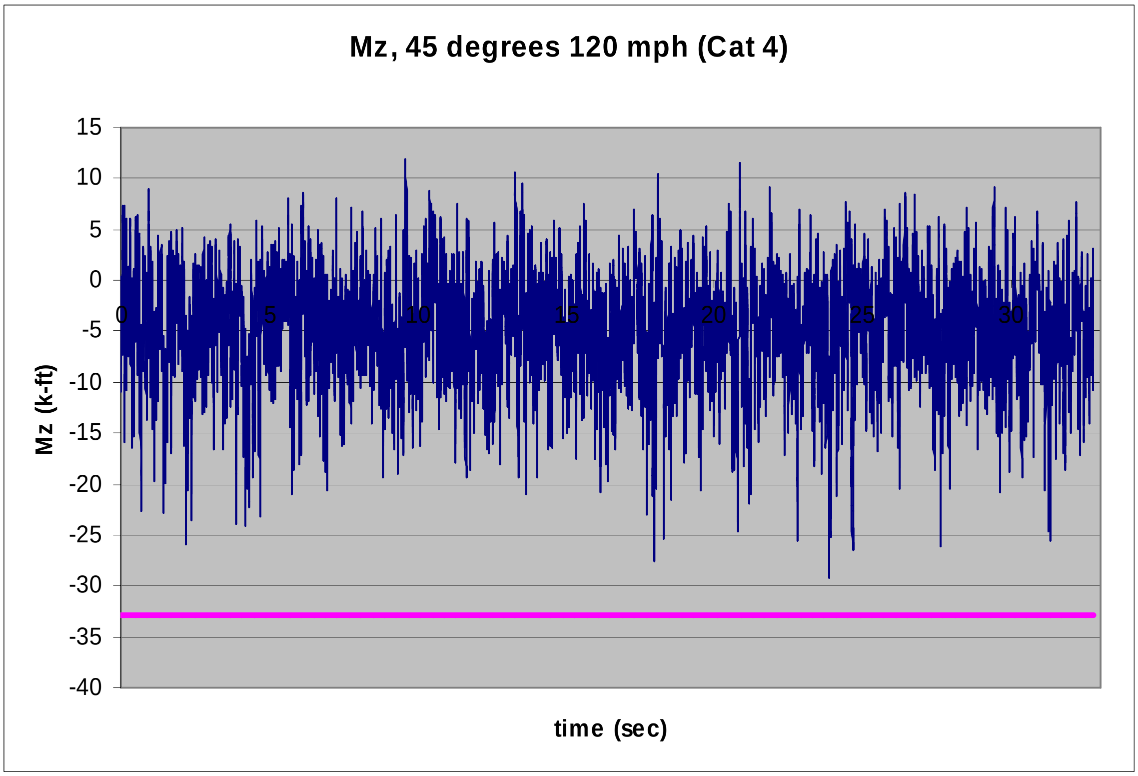

Figure 7.4-Time History for 16" Girder

Table 7.3-16" Girder Moment Results

16" x 16" Beam 1							
$Mz_{97''}$ (ft-kips)							
				No Window Protection		*Windows Protected*	
Angle	***Category***	***Wind Speed (mph)***	***M_{cr}***	***Max M_z***	***Pass/ Fail***	***Max M_z***	***Pass/ Fail***
0	Cat 4	105	-32.95	-18.39	Pass	-14.92	Pass
	CAT 5	115	-32.95	-24.56	Pass	-20.40	Pass
		120	-32.95	-27.86	Pass	-23.33	Pass
		125	-32.95	-31.30	Pass	-26.39	Pass
		131	-32.95	-35.61	Fail	-30.21	Pass
15	CAT 5	115	-32.95	-25.57	Pass	-21.83	Pass
		120	-32.95	-28.96	Pass	-24.88	Pass
		125	-32.95	-32.49	Pass	-28.07	Pass
		131	-32.95	-36.92	Fail	-32.06	Pass
30	CAT 5	115	-32.95	-26.48	Pass	-24.18	Pass
		120	-32.95	-29.94	Pass	-27.45	Pass
		125	-32.95	-33.56	Fail	-30.85	Pass
		131	-32.95	-38.09	Fail	-35.12	Fail
45	CAT 5	115	-32.95	-26.56	Pass	-22.94	Pass
		120	-32.95	-30.04	Pass	-26.09	Pass
		125	-32.95	-33.66	Fail	-29.38	Pass
		131	-32.95	-38.21	Fail	-33.51	Fail
60	CAT 5	115	-32.95	-24.58	Pass	-22.29	Pass
		120	-32.95	-27.88	Pass	-25.38	Pass
		125	-32.95	-31.32	Pass	-28.61	Pass
		131	-32.95	-35.63	Fail	-32.66	Pass
75	CAT 5	115	-32.95	-17.36	Pass	-15.06	Pass
		120	-32.95	-20.02	Pass	-17.52	Pass
		125	-32.95	-22.79	Pass	-20.08	Pass
		131	-32.95	-26.26	Pass	-23.29	Pass
90	CAT 5	120	-32.95	-9.78	Pass	-9.42	Pass
		125	-32.95	-11.68	Pass	-11.29	Pass
		131	-32.95	-14.07	Pass	-13.64	Pass

Table 7.4-6" Deep Pan Moment results

4" x 6" Joist 4							
$Mz_{midspan}$ (ft-kips)							
				No Window Protection		*Windows Protected*	
Angle	***Category***	***Wind Speed***	***Mcr***	***Max Mz***	***Pass/ Fail***	***Max Mz***	***Pass/ Fail***
0	CAT 5	110	-7.89	3.30	Pass	-3.31	Pass
		115	-7.89	3.99	Pass	-3.63	Pass
		120	-7.89	4.36	Pass	-3.97	Pass
		125	-7.89	4.74	Pass	-4.32	Pass
		131	-7.89	5.23	Pass	-4.76	Pass
15	CAT 5	115	-7.89	-4.49	Pass	-4.27	Pass
		120	-7.89	-4.90	Pass	-4.66	Pass
		131	-7.89	-5.87	Pass	-5.58	Pass
30	CAT 5	115	-7.89	-4.95	Pass	-4.73	Pass
		120	-7.89	-5.40	Pass	-5.17	Pass
		125	-7.89	-5.88	Pass	-5.62	Pass
		131	-7.89	-6.47	Pass	-6.18	Pass
45	CAT 5	115	-7.89	-5.35	Pass	-4.43	Pass
		120	-7.89	-5.84	Pass	-4.85	Pass
		125	-7.89	-6.35	Pass	-5.29	Pass
		131	-7.89	-6.99	Pass	-6.34	Pass
60	CAT 5	115	-7.89	-6.03	Pass	-5.81	Pass
		120	-7.89	-6.58	Pass	-6.34	Pass
		125	-7.89	-7.15	Pass	-6.89	Pass
		131	-7.89	-7.87	Pass	-7.58	Pass
75	CAT 5	115	-7.89	-4.69	Pass	-4.47	Pass
		120	-7.89	-5.12	Pass	-4.88	Pass
		125	-7.89	-5.57	Pass	-5.31	Pass
		131	-7.89	-6.13	Pass	-5.85	Pass
90	CAT 5	120	-7.89	-3.10	Pass	-2.86	Pass
		125	-7.89	-3.37	Pass	-3.12	Pass
		131	-7.89	-3.72	Pass	-3.44	Pass

7.4 Cladding Analysis

7.4.1 Cladding Integrity

At the time of construction, the current building code required all commercial windows have capabilities to withstand pressures of 20 pounds per square foot (psf). The designer's intuition was that 20 psf was to low; therefore, he designed, specified, and physically tested each window for 40 psf (Blessy, 2004). Impact resistant glass was seldom used in the 1960's due to lacking knowledge of wind-borne debris from hurricanes and product availability, and was not used in any of the buildings Mr. Blessey designed and constructed for the hospital.

7.4.2 Pressure Results

Using equation 7.3 the positive and negative peak pressures for window taps are presented in tables 7.5 & 7.6. Treating the components and cladding as partially enclosed ended up with windows failing at category 1 levels and data presented in tables 7.5 & 7.6 are for enclosed conditions. Although the South Wing should be evaluated as partially enclosed, presenting the results as enclosed shows how even if the envelope is not breached the windows can only withstand a category 2 hurricane.

Comparing to the original design pressure, pressures greater than 40 psf and lower than -40 psf are shaded in. Although anything greater than the design pressure does not necessarily mean entire window failure, it illustrates that the windows were under designed for hurricane force pressures.

Table 7.5a-Positive Peak Pressure

P08		*CAT 1*	*CAT 2*	*CAT 3*	*CAT 4*	*CAT 5*
Tap	Cp			P (lbf)		
1A01	2.48	24.5	35.3	50.3	75.0	116.8
1A02	3.02	29.5	42.5	60.6	90.4	140.7
1A03	3.13	30.5	44.0	62.7	93.5	145.6
1A04	2.73	26.8	38.6	55.1	82.2	127.9
2A01	3.12	30.4	43.8	62.4	93.1	144.9
2C01	1.81	18.3	26.4	37.6	56.1	87.3
2C02	3.45	33.5	48.2	68.8	102.6	159.7
2C03	3.53	34.2	49.2	70.2	104.7	163.0
2C04	3.05	29.8	42.9	61.1	91.1	141.9
2C05	2.31	22.9	33.0	47.1	70.2	109.3
3A01	3.24	31.5	45.4	64.7	96.5	150.2
3A02	3.42	33.2	47.8	68.2	101.7	158.2
3A03	3.72	36.0	51.8	73.9	110.2	171.5

P10		*CAT 1*	*CAT 2*	*CAT 3*	*CAT 4*	*CAT 5*
Tap	Cp			P (lbf)		
5B02	2.30	22.9	32.9	47.0	70.0	108.9
5C01	3.94	38.0	54.7	78.0	116.3	181.1
5C02	3.99	38.4	55.3	78.9	117.6	183.1
5C03	4.19	40.3	58.0	82.8	123.4	192.0
5C04	3.87	37.3	53.7	76.6	114.2	177.8
5D01	3.50	33.9	48.8	69.6	103.7	161.5
5F01	2.40	23.7	34.2	48.8	72.7	113.2
5F02	2.19	21.8	31.4	44.9	66.9	104.1
6D01	4.38	42.0	60.5	86.3	128.6	200.1
6D02	3.94	38.0	54.7	78.1	116.4	181.2
6F01	3.08	30.1	43.3	61.8	92.1	143.3
6F02	2.40	23.8	34.3	48.9	72.9	113.4
7B01	4.20	40.3	58.1	82.9	123.5	192.3

P09		CAT 1	CAT 2	CAT 3	CAT 4	CAT 5
Tap	Cp			P (lbf)		
3B01	3.10	30.2	43.5	62.0	92.4	143.9
3B02	2.18	21.7	31.3	44.6	66.5	103.6
3C01	3.66	35.3	50.9	72.6	108.3	168.5
3C02	2.46	24.3	35.0	49.9	74.4	115.9
4A01	4.00	38.6	55.5	79.2	118.1	183.8
4C01	4.02	38.7	55.8	79.5	118.6	184.6
4C02	3.70	35.8	51.5	73.5	109.6	170.6
4C04	3.44	33.4	48.1	68.6	102.2	159.1
4C05	2.93	28.7	41.3	59.0	87.9	136.8
5A01	3.81	36.8	53.0	75.5	112.6	175.3
5A02	3.92	37.8	54.4	77.6	115.7	180.0
5A03	3.98	38.4	55.2	78.8	117.4	182.8
5B01	3.21	31.2	45.0	64.1	95.6	148.8

P07		CAT 1	CAT 2	CAT 3	CAT 4	CAT 5
Tap	Cp			P (lbf)		
6A01	1.99	20.0	28.8	41.0	61.1	95.2
6A02	3.14	30.6	44.0	62.8	93.7	145.8
6A03	3.67	35.5	51.1	72.9	108.6	169.0
6A04	3.91	37.7	54.3	77.5	115.5	179.8
6A05	4.19	40.3	58.0	82.8	123.4	192.1
7A01	4.09	39.3	56.6	80.8	120.4	187.4
7A02	3.80	36.7	52.9	75.4	112.4	175.0
7A03	4.11	39.5	56.9	81.2	121.1	188.4
7A04	3.98	38.3	55.2	78.8	117.4	182.8
7A05	4.54	43.5	62.6	89.3	133.2	207.3
7A06	4.24	40.7	58.6	83.6	124.7	194.0
7C05	4.45	42.7	61.5	87.7	130.8	203.5
00J01	1.88	19.0	27.3	39.0	58.1	90.5

Table 7.5b-Positive Peak Pressures

P06		*CAT 1*	*CAT 2*	*CAT 3*	*CAT 4*	*CAT 5*
Tap	Cp			P (lbf)		
6C01	4.27	41.0	59.0	84.2	125.5	195.3
6C02	4.31	41.3	59.5	84.9	126.6	197.1
6C03	4.31	41.4	59.6	85.0	126.7	197.3
6C04	4.41	42.3	61.0	87.0	129.6	201.8
6C05	3.58	34.6	49.8	71.1	106.0	165.0
7C01	4.31	41.4	59.6	85.0	126.7	197.2
7C02	4.58	43.9	63.2	90.2	134.4	209.3
7C03	4.46	42.8	61.6	87.8	131.0	203.8
7C04	4.56	43.7	63.0	89.8	133.9	208.5
7C06	4.15	39.9	57.5	82.0	122.2	190.2
7C07	4.45	42.7	61.5	87.7	130.8	203.6
7C08	4.00	38.5	55.4	79.1	117.9	183.4
7D01	4.40	42.2	60.8	86.7	129.3	201.2

P04		*CAT 1*	*CAT 2*	*CAT 3*	*CAT 4*	*CAT 5*
Tap	Cp			P (lbf)		
8A14	4.38	42.1	60.6	86.4	128.8	200.5
8A15	4.89	46.7	67.3	96.0	143.1	222.7
8B01	3.71	35.8	51.6	73.6	109.7	170.8
8B02	3.17	30.9	44.5	63.5	94.7	147.3
8C01	4.81	46.0	66.2	94.5	140.9	219.3
8C02	5.09	48.6	69.9	99.8	148.7	231.5
8C03	4.89	46.8	67.3	96.1	143.2	222.9
8C04	4.74	45.4	65.3	93.2	138.9	216.3
8C05	4.62	44.3	63.8	91.0	135.6	211.1
8C06	5.09	48.5	69.9	99.7	148.6	231.3
8C07	4.31	41.4	59.6	85.1	126.8	197.3
8C08	4.36	41.8	60.2	85.9	128.0	199.3
8C09	4.47	42.8	61.7	88.0	131.2	204.2

P01		CAT 1	CAT 2	CAT 3	CAT 4	CAT 5
Tap	Cp			P (lbf)		
8A01	2.54	25.1	36.1	51.5	76.8	119.5
8A02	4.13	39.7	57.2	81.6	121.6	189.2
8A03	3.96	38.2	55.0	78.4	116.9	182.0
8A04	4.31	41.3	59.5	85.0	126.6	197.1
8A05	4.28	41.1	59.2	84.4	125.9	195.9
8A06	4.07	39.1	56.4	80.4	119.9	186.6
8A07	4.46	42.7	61.6	87.8	130.9	203.8
8A08	4.33	41.6	59.9	85.4	127.3	198.1
8A09	4.30	41.3	59.4	84.8	126.3	196.6
8A10	4.32	41.5	59.7	85.2	127.0	197.7
8A11	4.51	43.2	62.2	88.8	132.3	206.0
8A12	4.45	42.7	61.5	87.8	130.8	203.6
8A13	4.95	47.3	68.1	97.1	144.8	225.4

P05		CAT 1	CAT 2	CAT 3	CAT 4	CAT 5
Tap	Cp			P (lbf)		
8C10	4.08	39.3	56.5	80.7	120.3	187.2
8C11	4.33	41.5	59.8	85.3	127.2	198.0
8C12	4.55	43.5	62.7	89.5	133.4	207.6
8C13	4.74	45.3	65.3	93.2	138.9	216.1
8C14	4.31	41.4	59.5	85.0	126.6	197.1
8D01	4.76	45.6	65.6	93.6	139.6	217.2
8D02	4.69	44.9	64.7	92.3	137.6	214.1
8F01	4.42	42.4	61.0	87.0	129.7	201.9
8F02	4.87	46.5	67.0	95.6	142.5	221.9
7E01	4.11	39.5	56.9	81.2	121.0	188.3
7E02	4.07	39.2	56.4	80.5	120.0	186.8
7F01	3.85	37.2	53.5	76.3	113.8	177.1
7F02	4.28	41.1	59.2	84.5	126.0	196.1

Table 7.6a-Negative Peak Pressures

P08		*CAT 1*	*CAT 2*	*CAT 3*	*CAT 4*	*CAT 5*
Tap	Cp			P (psf)		
1A01	-1.88	-18.0	-25.9	-36.9	-55.1	-85.7
1A02	-1.97	-18.8	-27.1	-38.6	-57.6	-89.6
1A03	-2.05	-19.5	-28.1	-40.1	-59.8	-93.1
1A04	-2.76	-26.0	-37.5	-53.5	-79.7	-124.1
2A01	-3.11	-29.5	-42.2	-60.6	-90.4	-140.7
2C01	-2.58	-24.6	-35.5	-50.6	-75.5	-117.5
2C02	-2.47	-23.6	-34.0	-48.5	-72.3	-112.5
2C03	-2.39	-22.9	-32.9	-47.0	-70.1	-109.0
2C04	-2.26	-21.6	-31.2	-44.5	-66.3	-103.2
2C05	-2.03	-19.6	-28.2	-40.2	-60.0	-93.4
3A01	-1.94	-18.9	-27.3	-38.9	-58.0	-90.2
3A02	-2.17	-21.0	-30.3	-43.2	-64.4	-100.2
3A03	-3.42	-32.5	-46.9	-66.9	-99.7	-155.1

P10		*CAT 1*	*CAT 2*	*CAT 3*	*CAT 4*	*CAT 5*
Tap	Cp			P (psf)		
5B02	-4.28	-40.8	-58.7	-83.8	-124.9	-194.4
5C01	-3.37	-32.3	-46.6	-66.4	-99.0	-154.2
5C02	-3.04	-29.3	-42.2	-60.2	-89.7	-139.6
5C03	-2.91	-28.2	-40.5	-57.8	-86.2	-134.2
5C04	-3.51	-33.6	-48.4	-69.1	-103.0	-160.4
5D01	-3.51	-33.7	-48.5	-69.2	-103.1	-160.5
5F01	-3.26	-31.3	-45.1	-64.4	-96.0	-149.4
5F02	-2.84	-27.5	-39.6	-56.4	-84.1	-130.9
6D01	-4.24	-40.5	-58.3	-83.2	-124.0	-193.0
6D02	-2.29	-22.5	-32.4	-46.2	-68.9	-107.3
6F01	-4.63	-44.1	-63.5	-90.6	-135.0	-210.1
6F02	-4.10	-39.2	-56.5	-80.6	-120.1	-187.0
7B01	-3.86	-37.1	-53.4	-76.2	-113.6	-176.8

P09		CAT 1	CAT 2	CAT 3	CAT 4	CAT 5
Tap	Cp			P (psf)		
3B01	-5.29	-49.8	-71.7	-102.3	-152.5	-237.4
3B02	-4.47	-42.2	-60.8	-86.8	-129.3	-201.3
3C01	-3.54	-33.6	-48.4	-69.1	-103.0	-160.3
3C02	-4.02	-38.1	-54.8	-78.2	-116.6	-181.5
4A01	-4.56	-43.2	-62.2	-88.7	-132.3	-205.9
4C01	-3.39	-32.4	-46.6	-66.5	-99.1	-154.3
4C02	-3.36	-32.1	-46.3	-66.0	-98.4	-153.2
4C04	-2.46	-23.8	-34.3	-49.0	-73.0	-113.6
4C05	-4.06	-38.6	-55.6	-79.4	-118.3	-184.1
5A01	-2.19	-21.5	-31.0	-44.2	-65.8	-102.5
5A02	-2.04	-20.1	-28.9	-41.3	-61.6	-95.8
5A03	-5.14	-48.7	-70.1	-100.1	-149.2	-232.2
5B01	-3.75	-35.8	-51.6	-73.6	-109.8	-170.9

P07		CAT 1	CAT 2	CAT 3	CAT 4	CAT 5
Tap	Cp			P (psf)		
6A01	-2.04	-20.2	-29.1	-41.6	-62.0	-96.4
6A02	-2.05	-20.3	-29.2	-41.7	-62.1	-96.7
6A03	-1.96	-19.5	-28.0	-40.0	-59.6	-92.7
6A04	-2.06	-20.4	-29.4	-41.9	-62.5	-97.3
6A05	-4.53	-43.2	-62.2	-88.8	-132.3	-206.0
7A01	-2.97	-29.1	-41.7	-59.5	-88.7	-138.0
7A02	-2.01	-20.2	-28.8	-41.2	-61.4	-95.5
7A03	-2.05	-20.5	-29.4	-41.9	-62.5	-97.3
7A04	-2.23	-22.3	-31.9	-45.5	-67.8	-105.5
7A05	-2.23	-22.2	-31.8	-45.4	-67.6	-105.2
7A06	-5.04	-48.1	-69.1	-98.7	-147.1	-228.9
7C05	-3.28	-31.8	-45.7	-65.2	-97.2	-151.2
00J01	-5.62	-53.5	-77.0	-109.9	-163.8	-254.9

Table 7.6b-Negative Peak Pressures

P06		*CAT 1*	*CAT 2*	*CAT 3*	*CAT 4*	*CAT 5*
Tap	Cp			P (psf)		
6C01	-3.72	-35.7	-51.4	-73.3	-109.3	-170.1
6C02	-3.36	-32.4	-46.6	-66.5	-99.1	-154.2
6C03	-3.24	-31.3	-45.0	-64.2	-95.8	-149.1
6C04	-2.23	-22.0	-31.6	-45.1	-67.2	-104.6
6C05	-3.44	-33.2	-47.7	-68.1	-101.5	-158.1
7C01	-3.84	-36.9	-63.2	-75.8	-113.0	-175.8
7C02	-3.12	-30.3	-53.8	-62.3	-92.9	-144.6
7C03	-3.24	-31.4	-55.3	-64.4	-96.1	-149.5
7C04	-3.39	-32.8	-57.3	-67.4	-100.5	-156.4
7C06	-3.03	-29.5	-52.6	-60.6	-90.3	-140.6
7C07	-2.70	-26.4	-48.2	-54.3	-81.0	-126.1
7C08	-3.15	-30.6	-54.1	-62.8	-93.7	-145.8
7D01	-3.20	-31.0	-54.7	-63.7	-95.0	-147.9

P04		*CAT 1*	*CAT 2*	*CAT 3*	*CAT 4*	*CAT 5*
Tap	Cp		P (psf)			
8A14	-5.02	-47.9	-69.0	-98.4	-146.7	-228.3
8A15	-4.33	-41.5	-59.8	-85.3	-127.2	-197.9
8B01	-4.37	-41.9	-60.3	-86.1	-128.3	-199.7
8B02	-4.86	-46.4	-66.8	-95.3	-142.1	-221.1
8C01	-4.88	-46.6	-67.1	-95.7	-142.7	-222.1
8C02	-3.64	-35.2	-50.7	-72.4	-107.9	-167.9
8C03	-4.00	-38.5	-55.5	-79.2	-118.0	-183.7
8C04	-3.25	-31.6	-45.4	-64.8	-96.6	-150.4
8C05	-3.85	-37.1	-53.4	-76.2	-113.7	-176.9
8C06	-3.50	-33.9	-48.9	-69.7	-103.9	-161.7
8C07	-5.04	-48.1	-69.2	-98.8	-147.3	-229.2
8C08	-3.91	-37.7	-54.3	-77.5	-115.5	-179.7
8C09	-4.57	-43.8	-63.1	-90.0	-134.1	-208.8

P01		CAT 1	CAT 2	CAT 3	CAT 4	CAT 5
Tap	Cp			P (psf)		
8A01	-2.40	-23.8	-34.3	-48.9	-72.9	-113.5
8A02	-4.68	-44.8	-64.5	-92.1	-137.2	-213.6
8A03	-4.21	-40.5	-58.3	-83.2	-124.0	-193.0
8A04	-2.41	-23.8	-34.3	-49.0	-73.0	-113.6
8A05	-2.56	-25.2	-36.3	-51.8	-77.3	-120.3
8A06	-2.36	-23.4	-33.7	-48.0	-71.6	-111.5
8A07	-3.26	-31.7	-45.6	-65.1	-97.0	-151.0
8A08	-3.20	-31.2	-44.9	-64.0	-95.5	-148.6
8A09	-2.99	-29.2	-42.0	-59.9	-89.3	-139.1
8A10	-3.28	-31.9	-45.9	-65.4	-97.6	-151.8
8A11	-2.67	-26.3	-37.8	-54.0	-80.4	-125.2
8A12	-3.04	-29.7	-42.7	-61.0	-90.9	-141.5
8A13	-2.61	-25.7	-37.1	-52.9	-78.8	-122.7

P05		CAT 1	CAT 2	CAT 3	CAT 4	CAT 5
Tap	Cp		P (psf)			
8C10	-3.45	-33.4	-48.1	-68.7	-102.4	-159.4
8C11	-5.11	-48.7	-70.1	-100.0	-149.1	-232.1
8C12	-3.42	-33.2	-47.8	-68.2	-101.6	-158.1
8C13	-3.65	-35.3	-50.8	-72.5	-108.1	-168.2
8C14	-3.20	-31.1	-44.8	-63.9	-95.2	-148.2
8D01	-2.99	-29.2	-42.0	-59.9	-89.3	-139.1
8D02	-2.42	-23.9	-34.5	-49.2	-73.3	-114.2
8F01	-5.57	-53.0	-76.3	-108.8	-162.3	-252.6
8F02	-4.23	-40.6	-58.5	-83.5	-124.4	-193.7
7E01	-2.41	-23.7	-34.2	-48.7	-72.6	-113.1
7E02	-4.65	-44.4	-63.9	-91.1	-135.8	-211.4
7F01	-5.02	-47.8	-68.8	-98.2	-146.4	-227.8
7F02	-4.24	-40.6	-58.4	-83.4	-124.3	-193.4

7.4.3 Window Design Pressures

Although it was determined the design pressures for the original windows were 40 psf, the windows are now 40 years old and should be reevaluated under current codes. Using ASTM E 1300 (ASTM, 2003) charts for 60" x 61" x 7/32" annealed glass supported on four sides with a failure rate of eight per thousand the pressure is 42 psf over a twenty year period. Normally, the first twenty years a window will loose 10%-20% of its original strength and an extra 5% - 10% over another twenty years (Minor, 2004), which results in a 40-year life design pressure of 40 psf.

ASTM E 1300 does allow an increasing in the failure rate from 0 to 50 per thousand. At a failure rate of 50 per thousand the design pressure would increase to 50 psf. Regardless, revaluating tables 7.2 & 7.3 the windows are still severely under designed for hurricane force winds.

7.4.4 Wind-Borne Debris

Numerous roofs in the hospital complex, as well as neighboring roofs, have gravel topping. Since the windows are not impact resistant, they will break when impacted by this topping and expose the structure to hurricane related elements. Unlike failure due to high pressures, all windows in the South Wing that encounter wind-borne debris have the potential to fail. Ground floor windows generally have the highest probability of failure due to loose debris from neighboring areas. However, when comparing upper floor (2^{nd} – 5^{th}) windows that are level with and face a gravel-topped roof to ground level windows, both are considered to have equal risk of breaking. Upper floor windows adjacent to gravel toped roofs will encounter loose debris and break, but the magnitude of wind borne debris will be much less than that which comes in contact with ground floor windows.

7.5 Electrical and Mechanical Systems Analysis

Although the hospital has back-up generators they are located on the 1st floor of the hospital. Reviewing the flood levels in table 5.1 the hospital can expect flooding in a Category 3 hurricane or greater and also expect to loose primary and back-up power in these scenario's.

CHAPTER 8: SHELTER ANALYSIS AND RECOMMENDATIONS

8.1 Introduction

The purpose of the shelter analysis is to provide a simple to use set of operational plans for different hurricane scenarios. These plans identify the different parts of the hospital complex that are vulnerable to wind and flood hazards; including plans on where to move highly vulnerable to areas with less vulnerability. To accomplish this, results from chapters 5, 6, and 7 were evaluated and compiled to obtain an overview of how the hospital would perform in different hurricane scenarios. Areas in the hospital were broken down into three levels of hazards, high, moderate, and low; allowing West Jefferson Medical Center to place evacuees in areas with a lower hazard first and so on, until their sheltering needs are meet. Although the wind tunnel analysis was only conducted on the South Wing, results would be used to evaluate the entire West Jefferson Medical Center campus except for the two doctor's towers.

8.2 Shelter Plan

The shelter report contains two different Wind sheltering plans and three different Flood sheltering plans. These plans are used in different combinations depending on the various threats posed by the approaching hurricane.

Defined in section 3.11, the Wind and Flood plans are color-coded based on hazard level; green, low hazard; yellow, moderate hazard; red, high hazard; and gray indicating temporary walkways. Each area of the hospital was evaluated and placed in the appropriate hazard level. Figure 8.1 is an example of a Wind shelter plan for the 2nd floor of the entire hospital. For the entire set of Wind and Flood shelter plans refer to Appendix F and F1.

For the Wind shelter plan, majority of the interior areas that did not have exterior windows were categorized as low hazards. Areas with exterior windows were classified as moderate hazard except those that had a direct threat of being compromised, i.e. wind-borne debris.

Figure 8.1-2nd Floor Wind 2 Shelter Plan

The Flood shelter plan was primarily based on the flood analysis and table 5.1. Flood 0 is intended for zero to a minimal flood scenario, flood 1 for 1st floor flooding, and flood 2 for 2nd floor flooding.

Table 8.1, the Hurricane Sheltering Plan Selection Matrix, combines the Wind and Flood plans based on approaching intensity and direction. The “hurricane direction of travel” is the anticipated storm track (i.e., the direction of motion of the storm). The flood plan used also depends on the astronomical tide expected when the storm makes landfall (either high tide or mean tide). The flood depths indicated are a range of possible values determined from table 5.1. These values are the expected flood levels in the hospital site and do not include additional water levels from rainfall flooding, which could add as much as 1-2 feet to the given values.

To determine the correct storm shelter plan for a given hurricane, first determine the expected hurricane intensity at landfall and the direction of travel, both can be obtained from the National Hurricane Center advisories, the local emergency management office, or National Weather Service office. Next, the appropriate Wind and Flood sheltering plans should be combined, creating the overall shelter plan. When combining the Wind or Flood plans, areas that are red take precedence and areas that are yellow override areas in green.

8.3 Department Relocation Plan

If a portion of the structure housing a critical department is identified as having high hazard on either of the wind plan or the flood plan, the department relocation table, table 8.2, should be used to determine the department's new location. Areas that have an assigned relocation in table 8.2 were previously determined by the hospital and areas that are left blank should be filled out by the hospital prior to hurricane season.

Table 8.1- Hurricane Sheltering Plan Selection Matrix

<table>
<tr><th rowspan="2">Predicted Saffir-Simpson Hurricane Category at Landfall</th><th rowspan="2">Hurricane Direction of Travel</th><th colspan="2">Storm Surge at Mean Tide</th><th colspan="2">Storm Surge at High Tide</th><th rowspan="2">Sustained Wind (mph)**</th><th rowspan="2">Peak Gust (mph)**</th><th rowspan="2">Wind Sheltering Plan</th></tr>
<tr><th>Flood Depth* (ft)</th><th>Flood Sheltering Plan</th><th>Flood Depth* (ft)</th><th>Flood Sheltering Plan</th></tr>
<tr><td>1</td><td>All</td><td>0</td><td>Flood 0</td><td>0</td><td>Flood 0</td><td>60 – 75</td><td>75 - 85</td><td>Wind 1</td></tr>
<tr><td rowspan="8">2</td><td>East North East</td><td rowspan="8">0</td><td rowspan="8">Flood 0</td><td rowspan="5">0 – 7</td><td rowspan="5">Flood 1</td><td rowspan="8">75 - 85</td><td rowspan="8">85 - 105</td><td rowspan="8">Wind 1</td></tr>
<tr><td>Northeast</td></tr>
<tr><td>North North East</td></tr>
<tr><td>North</td></tr>
<tr><td>North North West</td></tr>
<tr><td>Northwest</td><td rowspan="3">0</td><td rowspan="3">Flood 0</td></tr>
<tr><td>West North West</td></tr>
<tr><td>West</td></tr>
<tr><td rowspan="8">3</td><td>East North East</td><td rowspan="2">Up to 9</td><td rowspan="2">Flood 1</td><td rowspan="5">0 – 15</td><td rowspan="5">Flood 2</td><td rowspan="8">85 - 105</td><td rowspan="8">105 - 125</td><td rowspan="8">Wind 2</td></tr>
<tr><td>Northeast</td></tr>
<tr><td>North North East</td><td rowspan="3">Up to 11</td><td rowspan="3">Flood 1</td></tr>
<tr><td>North</td></tr>
<tr><td>North North West</td></tr>
<tr><td>Northwest</td><td>Up to 7</td><td>Flood 1</td><td rowspan="2">0 – 8</td><td rowspan="2">Flood 1</td></tr>
<tr><td>West North West</td><td rowspan="2">0</td><td rowspan="2">Flood 0</td></tr>
<tr><td>West</td><td>0</td><td>Flood 0</td></tr>
<tr><td rowspan="8">4</td><td>East North East</td><td rowspan="5">Up to 16</td><td rowspan="5">Flood 2</td><td rowspan="6">0 – 17</td><td rowspan="6">Flood 2</td><td rowspan="8">105 - 150</td><td rowspan="8">125 - 190</td><td rowspan="8">Wind 2</td></tr>
<tr><td>Northeast</td></tr>
<tr><td>North North East</td></tr>
<tr><td>North</td></tr>
<tr><td>North North West</td></tr>
<tr><td>Northwest</td><td>Up to 8</td><td rowspan="3">Flood 1</td></tr>
<tr><td>West North West</td><td rowspan="2">Up to 2</td><td rowspan="2">0 – 10</td><td rowspan="2">Flood 1</td></tr>
<tr><td>West</td></tr>
<tr><td rowspan="8">5</td><td>East North East</td><td rowspan="6">Up to 19</td><td rowspan="8">Flood 2</td><td rowspan="6">0 – 19</td><td rowspan="8">Flood 2</td><td rowspan="8">> 150</td><td rowspan="8">> 190</td><td rowspan="8">Wind 2</td></tr>
<tr><td>Northeast</td></tr>
<tr><td>North North East</td></tr>
<tr><td>North</td></tr>
<tr><td>North North West</td></tr>
<tr><td>Northwest</td></tr>
<tr><td>West North West</td><td rowspan="2">Up to 12</td><td rowspan="2">0 -12</td></tr>
<tr><td>West</td></tr>
</table>

Table 8.2-Department Relocation Plan

Department	Original Designated Evacuation Area	Wind 1 + Flood 0	Wind 1 + Flood 1	Wind 2 + Flood 0	Wind 2 + Flood 1	Wind 2 + Flood 2
Emergency Room	SDS	No move		No move		
Pharmacy	4 West Rehab Kitchen Area	No move	4 West Rehab Kitchen Area	No move		
Purchasing	Lounge Areas 5th & 7th Floor	No move	Lounge Areas 5th & 7th Floor			
Housekeeping	4 West Diabetes Classroom	No move	4 West Diabetes Classroom			
Radiology	ICU/CCU	No move	ICU/CCU	No move		
Nuclear/Radiation	Surgery	No move	Surgery	No move	Surgery	
Biomedical	8th Floor Physical Therapy Dept	No move	8th Floor Physical Therapy Dept.	No move		
Lab	5th South B wing Close to exterior stairwell	No move	5th floor South Wing Close to exterior stairwell	No move	5th floor South Wing	5th floor South Wing
Maintenance	5 South B wing	No move	5 South B wing	No move		
Central Control	Same Day Surgery Waiting					
Child Care	4 West Rehab	No move	4 West Rehab	No move	4 West Rehab	4 West Rehab
ICU/CCU		No move	No move			

CHAPTER 9: MITIGATION ANALYSIS AND RECOMMENDATIONS

9.1 Introduction

Using the results and analysis from previous chapters, the following are recommendations and mitigation strategies for West Jefferson Medical Center's anticipated hurricane scenarios. The recommendation portion summarizes why certain areas should not be used and makes short-term recommendations. Whereas the mitigation strategies portion investigates future ideas and products emergency officials can take advantage of to improve the hospital's use as a hurricane shelter, relative to the present costs of these improvements. A full copy of the mitigation report can be found in Appendix G and corresponding figures in appendix G1.

9.2 High Hazard Areas

In order to provide appropriate recommendations and mitigation strategies, areas found to have high hazards in the Wind and Flood plans were separated from the moderate and low hazardous areas and presented in table 9.1 and 9.2. Isolating the high hazard areas to provide additional information about the threat as it pertains to each shelter area enables emergency officials to make better decisions when determining which recommendation is most suitable.

9.3 Recommendations

9.3.1 Structural

It was determined that the 16" x 16" girder that support the roof do not have any top reinforcing steel at mid span, therefore, once the applied moments are greater than the girders cracking moment the roof will collapse. Section 7.3 determined that the 8th floor of the South Wing should not be used a during a Category 5 scenario. The ICU/CCU unit was also found to have potential roof failure. Unlike the South Wing, the ICU/CCU has a

Table 9.1-Category 3 or greater High Hazard Shelter Areas per Chapter 8

Shelter Area	Hazard
1st Floor	Flooding
2nd Floor	Flooding
8th Floor	Roof Uplift Pressures
ICU/CCU	Roof Uplift Pressure/ Wind-Borne Debris

Table 9.2-Category 3 or greater High Hazard Shelter Areas

Shelter Area	Hazard * Lay down due to trees
1st Floor	
Patient Registration	Wind-borne debris
Food Services	Wind-borne debris/ Lay down*
Elder Plus	Wind-borne debris/ Lay down*
South wing walkway	Wind-borne debris
Auditorium	Roof/ Lay down*
2nd Floor	
East side of Same Day Surgery	Wind-borne debris
Surgery waiting area	
Surgery (next to parking garage)	
Cardiology	
Nuclear Medicine	
Cardiac Rehab	
3rd Floor	
Telemetry	Wind-borne debris
Post Partum	
Nursery	
Delivery Offices	
Walkways	
4th Floor	
Medical Surgery	Wind-borne debris
Rehab	
Pediatrics	
Rehab Kitchen	
5th - 7th Floor	
Elevator Area	High External Pressures
Corner rooms	High Pressures
8th Floor	
Elevator Area	High External Pressures
Patient Rooms	

light-gage roof, which does not perform well under high winds. Therefore, it is recommended that these areas not be used for a Category 3 or greater hurricane.

9.3.2 Components and Cladding

With the existing windows being under designed for hurricane pressures and not designed for debris impact, some form of protection is needed. Replacing the windows with hurricane windows or installing storm shutters will protect the windows, rooms they are in and the entire shelter. If no protection or a product that does not protect the window area from high pressures is used, areas in yellow on the shelter report should be used with caution and be prepared to evacuate if necessary and areas in red not be used at all. To protect the facilities from falling debris, it is recommended that any loose objects be secured, tied down, or completely removed before a storm. Trees should be trimmed to minimize damage in the event they should fall. Currently the command center plans on operating out of the 4th floor rehab, which is an high hazard area due to wind-borne debris. Priority should be placed in obtaining window protection for this area and at the least plywood be installed.

9.3.3 Electrical and Mechanical System Mitigation

In order to maintain power from a direct hit by a Category 3 hurricane or greater the back-up generators need to be placed above the expected flood levels, which is the second floor for a Category 3 and 3rd floor for Category 4 and 5. On top of elevating the back-up generators, the control panel must also be elevated, otherwise, there will be no way on providing power throughout the hospital.

9.4 Window Protection

9.4.1 Overview

Replacing all the windows or providing hurricane shutters for the entire hospital can be expensive. However, in order to be fully functional as a special needs facility some type of protection has to be provided. Table 9.3 provides a brief comparison of hurricane window protection including their relative cost. Including different types of products available on the market and their relative cost allow the hospital to determine which products meet their needs, functionally and financially. Also, by including the cost throughout the mitigation report possible could assist in obtaining outside funding. All products in table 9.3, except plywood, comply with ASTM E 1986 and 1996. If a product that is not listed in table 9.3 is used, it must meet ASTM standards. Following table 9.3, each type of products advantages and disadvantages are discussed in the following sections and compiled into three mitigation strategies for the hospital.

9.4.2 Hurricane Resistant Windows

The South Wing has 287 windows, not including windows on the ninth and tenth floor mechanical tower. Installing most window protection will be difficult and costly. For floors two through eight, a lift or crane will be required in order to place the new windows.

Hurricane resistant windows are normally layers of heat-strengthened heat tempered or annealed glass with a layer of film between them (Appendix G1, Figure G1.1). The film layer extends outside the glass and is attached to a properly mounted frame. To comply with current standards, it is imperative the window frames are securely attached to the structure (Appendix G1, Figure G1.2). With hurricane resistant windows in place, there is no need for deployment or subsequent installation before a hurricane. This will provide continuous protection throughout the life of the building from hurricanes, as well as tornados. Adding hurricane windows to an existing building will have the high initial cost, roughly $300,000, but one of the lowest long-term cost through energy efficiency and minimal maintenance. However, in order to maintain the capabilities to withstand high pressures related to a category 4 hurricane or greater, non-

Table 9.3-Hurricane Window Protection

Product	**Brief Description**	**Fixed/ Permanent**	**Deployment Required**	**Installation Required**	**Storage**	**Can be Interior Mounted**	**Can Withstand High Pressures**	**Maintenance**	**Price per window (Materials Only)** **+ Includes Installation**
Hurricane Windows	Remove and replace windows with windows	✓					✓	None	\$1,000 - \$2,500
Automatic Roll Down Shutters	Roll down shutter system attached to front of each window or opening	✓	✓			✓	✓	High	\$2500 - \$3,000
Manual Roll Down Shutters		✓	✓			✓	✓	High	\$1,000 - \$2,000
Accordion Shutter	Accordion shutters	✓	✓			✓	✓	Moderate	\$700 - \$1,000
Storm Panels	Clear Acrylic, Steel or Aluminum panels installed on a preset track			✓	✓	✓	✓	Moderate	\$250 - \$500
Fabric Screens	Fabric screens placed over window			✓	✓	✓		Low	\$200 - \$500
	Large screen			✓	✓			Low	\$12 - \$14 per sq. ft.+
Aluminum Screens	Metal screen over opening	✓				✓		Low	\$1,500 - \$1,800
Plywood	5/8" or 3/4" thick precut plywood shutters			✓	✓	✓		Low	\$40 - \$50

operable hurricane window should be used. Operable hurricane windows still provide protection against high pressures but not near same magnitude as fixed.

9.4.3 Roll Down Shutters

Roll down shutters can be either mechanically or manually deployed. The ability to close the shutter from the inside makes them the most convenient type of shutter. A box containing a shutter is placed above each window and guided with a track when deployed (Appendix G1, Figures G1.3 & G1.4). As the hurricane approaches each shutter is deployed and left down until the hurricane completely passes. Mechanical shutters will reduce the time required to deploy, but with loss power they will operate the same as the manual shutter. Although roll down shutters are the strongest type of shutter, they only protect when deployed. Due to all the moving parts and operating on a track, roll down shutters are high maintenance. Mechanical shutters can cost about twice as much as the manual roll down shutters.

9.4.4 Accordion Shutters

Roll down shutter deploy vertically, where as accordion shutters deploy horizontally. The horizontal deployment allows one shutter to cover multiple windows that are in a row (Appendix G1, Figures G1.5 & G1.6). Accordion shutter will cost less than roll down shutters but have to be deployed from the exterior. For floors above ground level, exterior mounted accordion shutters are an impractical solution.

9.4.5 Storm Panels

Unlike roll down or accordion shutters, storm panels must be manually installed from the exterior on a pre-placed track. This can very labor intensive and only suggested for use in areas that can be easily reached. With the ability to choose acrylic, natural light will be able to enter the hospital (Appendix G1, Figure G1.7 & G1.8). Storm panels will have cheapest initial cost over all types of window protection meeting ASTM standards but their storage, maintenance of tracks, and installation per storm, will add to the long-term cost.

9.4.6 Large Fabric Screens

Shutters can be impractical for large openings, such as entrances, because they are cumbersome to close and open. Large fabric screens provide transparency, are lightweight, offer quick and easy installation, and provide equal protection against wind-borne debris (Appendix G1, Figures G1.9 – G1.12). They are also a practical solution for areas that are too large to shutter or panel. The prefabricated screens are placed over the desired openings and fastened to hooks anchored in predrilled holes.

9.4.7 Aluminum Screens

Hurricane screens are aluminum screens attached in front of an existing window or door. They enhance architectural details without obstructing views. They also can be opened and closed for maintenance and emergencies. Hurricane screens protect existing window by repelling wind-borne debris. Hinged at the top or side, hurricane screens are capable of being operable or fixed (Appendix G1, Figures G1.13 – G1.15). Permanently attached, no deployment or installation is needed before a hurricane. Hurricane screens will also provide shade and are energy efficient.

Air is still allowed to flow through the screen, subjecting the existing window to high hurricane pressures. In the upper floors, corners and sides, where high pressures are a factor, permanent screens will not provide sufficient protection.

9.4.8 Fabric Screens

Fabric screens are thick PVC coated woven polyester fabric sheet placed over an opening to protect from wind-borne debris. Predrilled pins are lined up with slots in the fabric sheet allowing a quick and easy installation (Appendix G1, Figures G1.16 & G1.17). As with the aluminum screens, fabric screens do not protect from high pressures.

9.4.9 Plywood

Although plywood does not comply with ASTM standards it is widely used because of cost and availability. If it is to be used as a temporary means of protection, the plywood must be precut and comply with the current International Building Code for plywood installation.

9.4.10 Other

Assuming the existing windows will break; sealed shutters can be placed from the interior instead of the exterior. With shutters on the inside of the building they will be easily accessible and time required to install and deploy will be lessened.

The above recommendations all comply fully or partially with ASTM standards. These standards are intended for protection of property instead of life safety. Since the hospital's primary goal is preserving life and safety, the integrity of the opening are more important than the windows themselves.

Table 9.4 lists the different shelter areas in the hospital and some recommended types of protection.

9.5 Window Mitigation Strategies

The intentions of table 9.5 and 9.6 are to show some of the many different mitigation strategies for the South Wing. *Mitigation 1,* hurricane windows, is an example of completely renovating the South Wing with impact resistant windows. The cost will be the highest of the three methods but once in place hurricane windows will provide constant protection without affecting the aesthetics of the building. According to West Jefferson Medical Center maintenance, the existing windows in the South Wing are breaking due to age and thermal stresses. Needing to replace the existing windows, using hurricane windows instead of laminated glass will avoid having to purchase new

Table 9.4-Suggested Window Protection

Shelter Area	Hurricane Windows	Roll Down Shutters	Accordion Shutters	Storm Panels	Window Screens	Plywood
General						
1st - 4th floor atrium waiting areas			✓		✓	
East wing	✓	✓			✓	
Walkways	✓		✓			
West wing	✓	✓			✓	
South Wing Emergency Exits	✓	✓	✓	✓	✓	✓
1st Floor						
1st Floor South Wing	✓	✓	✓	✓	✓	✓
Food Services	✓		✓		✓	✓
Education Classrooms	✓	✓	✓	✓	✓	✓
Maintenance	✓	✓	✓	✓	✓	✓
Cat Scan/ Pediatric Fast Track	✓		✓	✓	✓	✓
2nd Floor						
2nd - 7th floor South Wing	✓	✓			✓	
Cardiac Rehab	✓		✓		✓	
Nuclear Medicine	✓	✓	✓	✓	✓	✓
Cardiology	✓		✓	✓	✓	✓
ICU/ CCU	✓		✓		✓	
Same Day Surgery	✓	✓	✓	✓	✓	✓
Surgery (next to parking garage)	✓				✓	✓
3rd Floor						
Delivery Offices	✓	✓				
Telemetry (facing east)	✓	✓	✓	✓	✓	✓
Nursery	✓	✓	✓	✓	✓	✓
4th - 8th Floor						
South Wing 4th - 7th corners, elevator area	✓	✓				
Rehab	✓	✓				
Rehab Kitchen	✓	✓	✓	✓	✓	✓

windows and some type of hurricane protection. Initial cost still may be high but with the energy savings, hurricane windows will pay for themselves over the years. During installation, *mitigation 1* will require certain areas to be temporarily closed but with no deployment or storage necessary, *mitigation 1* is the most convenient of the three allowing maintenance to focus on other tasks before a storm. Depending on the fire plan, operable windows can be replaced with fixed windows but in the event of loss of air conditioning operable windows provide a great means of ventilation.

Mitigation 2, hurricane shutters, can cost about the same as the hurricane windows or more depending on if they are manually or mechanically operated. Externally fixed in front of each window, manual roll down shutters can take hours to deploy and if not properly kept up may not deploy at all.

Mitigation 3, window screens and storm panels, will cut cost by using large fabric screens and storm panels where accessible. The ground floor windows, defined in hospital integrity section, can have Lexan clear storm panels and be installed without any scaffolding. To protect from wind-borne debris fixed aluminum screens are used for the upper and top floors. The aluminum screens do not protect from high pressures and some window failure is expected for a direct hit from a category 2 or greater. The fixed aluminum screens do not require installation, the large fabric screens require minimal installation, where as, the storm panels are time consuming.

Table 9.7 lists some of the hurricane window protection companies that were used in this report. To obtain a complete list of approved products the following two web locations are recommended.

Miami-Dade County approval list
http://www.miamidade.gov/buildingcode/pc-search_app.asp

Texas Department of Insurance
www.tdi.state.tx.us/company/wind/prod.indexshu.html

Miami-Dade County has set the standards in hurricane protection and any hurricane window protection used should be on their approval list. Although, majority of products on the Texas department of insurance site are Miami-Dade approved, the TDI site is more user friendly and not as overwhelming.

Table 9.5-Mitigation Strategies for South Wing

Floor	Area	Number of Windows	Window Size (inches)	Mitigation 1	Mitigation 2*	Mitigation 3
1st	Front	32	60 x 138	Hurricane Glass	Roll Down Shutters	Storm Panels
	Cafeteria	17			Accordion Shutters	Large Fabric Screens
2nd	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens/ Storm Panels
	Emergency Exit	2	93 x 112			Large Fabric Screens
3rd	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
4th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
5th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
	Elevator area	7	46 x 114		Accordion Shutters	Aluminum Screens
6th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
	Elevator area	7	46 x 114		Accordion Shutters	Aluminum Screens
7th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
	Elevator area	7	46 x 114		Accordion Shutters	Aluminum Screens
8th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
	Elevator area	7	46 x 114		Accordion Shutters	Aluminum Screens

*Based on manual roll down shutters

Table 9.6-Estimated Cost of Mitigation Strategies

	Price with installation	**Advantages**	**Disadvantages**
Mitigation 1	$600,000 - 1.1 million	Energy Efficient No Deployment Old windows need to be replaced anyways Aesthetically pleasing	Disruption for initial installation Cost Operable does not provide maximum protection
Mitigation 2	$570,000 - $900,000	Strongest Easy Deployment	High Maintenance Cost about the same as hurricane windows
Mitigation 3	$350,000 - $500,000	Cost Easy Installation No loss of service during installation	storage does not protect against high pressures

Table 9.7-Hurricane Protection Companies

Product	Company	Product Name	Web site	Location	Contact Info
Hurricane Windows	Pella Windows	Hurricane Shield	www.pella.com	New Orleans, LA	504-834-7744
	Dependable Glass	Safety Plus	www.depglass.com	Covington, LA	1-800-338-2414
	Al Broward	Window Lock	www.1800hurricane.com	Ft. Lauderdale, FL	1-800-487-7422
Storm Shutters	Roll A Way		www.roll-a-way.com	St. Petersburg, FL	1-800-683-9505
	Coulter Hurricane Products		www.coulterhurricane.com	Hialeah Gardens, FL	1-800-533-4869
	Rolling Shield		www.rollingshield.com	Miami, FL	1-305-436-6661
	Rolsafe		www.rolsafe.com	Ft. Myers, FL	1-800-833-5486
	Custom Pavers and Hurricane Shutters		www.custom-pavers.com	Ft. Lauderdale, FL	1-954-771-8090
	Sentinel Storm Protection		www.napleshurricaneshutters.com	Naples, FL	1-239-596-9697
	AGI Group		www.stormshutters.com	Sarasota, FL	1-800-823-6677
Fabric Screens	Wayne-Dalton Corp	Fabric Shield	www.wayne-dalton.com	Pensacola, FL	1888-827-3667
Aluminum Screen	Phoenix	SureGuard	www.1800hurricane.com	Ft. Lauderdale, FL	1-800-487-7422
	Exeter	Storm Shield Barrier	www.stormshield.net	Palm City, FL	1-888-393-8373
Large Screen	Storm Catcher	Strom Catcher	www.stormcather.com		1-888-962-7283
	Savannah Sales	Armor Screen	www.hurricaneproducts.com		1-888-640-0850
	Hendee Enterprises, Inc	Force 12	www.foce12protection.com	Houston, TX	1-713-796-2322

CHAPTER 10: HURRICANE KATRINA

10.1 Overview

On August 29, 2005, Hurricane Katrina struck Plaquemines Parish, about 50 miles east of West Jefferson Medical Center with wind speeds of 140 mph which is a category 4 hurricane on the Saffir-Simpson scale. Surrounding parishes were devastated by the extreme winds and storm surge. Wind data collected in Belle Chasse, LA, 6 miles from West Jefferson Medical center reported peak wind speeds of 102-105 mph which fall under category 1 winds (FCMP, 2005). Fortunately, West Jefferson Medical Center was spared from the storm with no storm surge and minimal damage to their facilities. The hospital was on the weak side of the storm. Consequently, the majority of the storm surge Jefferson Parish saw was from Lake Pontchartrain, which is due north and on the opposite side of the Mississippi river from the hospital. This direction did not push any water from the Barataria Bay onto land, which allowed majority of the West Bank to stay dry. Figure 10.1 is an satellite image of hurricane Katrina on August 28th, 2005, and figure 10.2 the National Hurricane Center advisory for August 29th, 2005.

After the storm, the hospital reported first floor windows in the corridor between the doctor's tower and parking garage were blown out due to emergency officials entering and leaving during storm. Although windows in the remaining portions of the hospital held, excessive bowing was observed during the storm. Since the hospital did not receive any storm surge, back-up generators were able to provide the necessary power when primary power was lost. However, sanitation issues arose when the hospital lost water pressure and did not regain it until five days after the storm made landfall.

Figure 10.1-Sattelite Imagery of Hurricane Katrina August 28, 2005 (NASA, 2005)

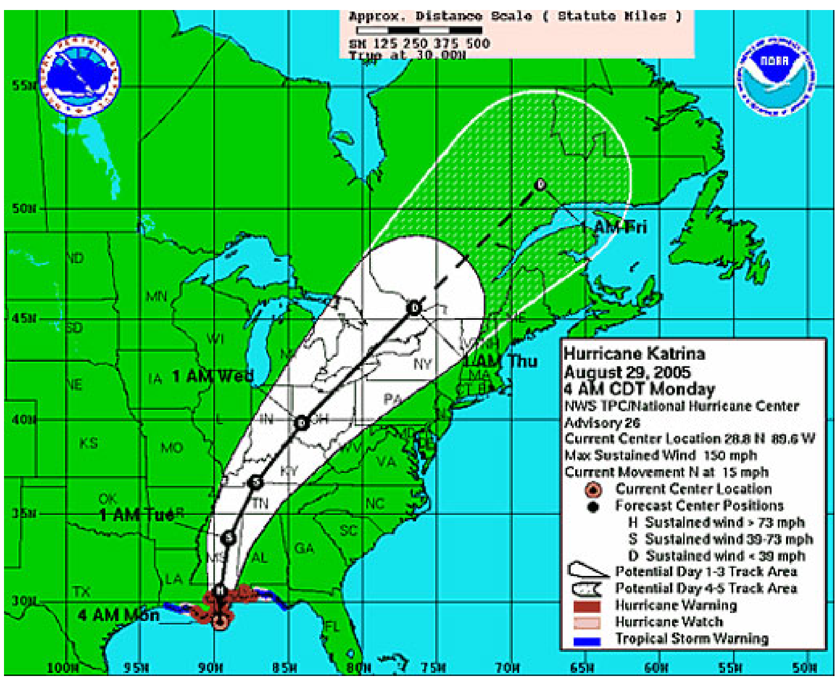

Figure 10.2-National Hurricane Center Advisory for Hurricane Katrina (NOAA, 2005e)

In reviewing other hospitals in New Orleans that did experience long term flooding, it was apparent the main problem was obtaining supplies. With no running water, functioning sewer system, and no fuel for back-up generators that were not flooded, they were unable to function. Some hospitals that tried to evacuate patients following the storm found main entrances and walkways between buildings inaccessible due to flooding. With no food, water, medical supplies, and communication for several days most people in these hospitals were in critical condition. The majority of critical patients were evacuated by helicopter.

10.2 West Jefferson Medical Center Application of the Adopted Method

In 2004, the New Orleans area was threatened by Hurricane Ivan, which made landfall as a category 3 near Gulf Shores, Alabama. The New Orleans areas saw sustained wind speeds around 40 mph (NOAA, 2005f). At that time the wind tunnel tests had been finalized and a draft of the Shelter and Mitigation Reports were completed and presented to the hospital. Although the hospital did not use these reports for Ivan, they followed recommendations in preparing for the 2005 hurricane season and particularly Hurricane Katrina.

Realizing that back-up generators would not function once a hurricanes storm surge rose above their first floor elevation, which was possible in a category 3 hurricane, the hospital began construction of a new building that moved their back-up generators and control panels to a second floor. Ironically, they were weeks away from finishing the project when Katrina struck and the back-up generators were still located on the first floor.

Although, the hospital did not replace or protect the windows in the South Wing, they did boarded up the windows in their command center on the 4th floor and have plans to replace all their gravel roofs.

During the storm, the hospital closely followed the portion in the Shelter Report on where to place patients. Areas and buildings that were considered high hazards were not used and those departments were relocated using the department relocation plan, table 8.2. Overall, the hospital was very appreciative of the reports and found them helpful in making important decisions to better protect their patients, staff, and their facility.

CHAPTER 11: CONCLUSIONS

11.1 Conclusions

In order to overcome some of the problems associated with shelter selections and operational planning, the goal of this thesis was to develop a new methodology for evaluating buildings for suitable use as hurricane shelters. This methodology quantitatively assesses shelters on their expected performance under different hurricane scenarios and classified them into risk levels, rather than the more qualitative pass/fail approach taken by the least-risk method currently in use.

This methodology was applied on a real case study to the West Jefferson Medical Center (WJMC), which planned to operate as a special needs shelter in up to a category 5 hurricane. A shelter operations plan and a mitigation plan were developed. The developed methodology is described through its application to the case study in the following paragraphs.

Plans for the WJMC facility were obtained and reviewed, and an onsite inspection was conducted. A flood analysis was conducted was based on all possible hurricane directions and intensities modeled in SLOSH to determine likely flood levels inside West Jefferson Medical Center for different storm conditions.

Using the adopted method with the Saffir-Simpson hurricane scale replacing the ASCE 7-02 wind speed map, wind speeds were related to the five categories of the Saffir-Simpson hurricane scale and adjusted for decrease in wind speeds at landfall and over land for the shelter site. To determine the wind speeds the shelter would receive, Vickery's wind speeds at landfall, table 3.4, were used as a basis for design wind velocities, and the decrease in wind speeds were applied and the design velocities for the appropriate shelter area.

Velocity pressures were determined using ASCE 7-02 with values for design velocities adjusted according to the Saffir-Simpson scale instead of the ASCE 7 wind map; the importance factor changed to 1.0; the directionality factor changed to 0.95 as recommended in Easley (2003); and the shelter was treated as partially enclosed and enclosed only if mitigation strategies followed. Wind tunnel tests were conducted on a 1:200 model of the South Wing using exposure B flow conditions. Structural analysis was completed using wind tunnel results and a finite element program. It was determined that 16″ x 16″ girders which support the roof have continuous reinforcing only at the bottom and the top has a seven foot break at mid-span where there is no reinforcing steel; therefore, without top reinforcing steel under uplift once the girders cracking moment is reached, the girder will fail. A cracking moment of 32.95 k-ft was determined as a failure state and influence factors for the specified girder supporting the roof on the South Wing were obtained using a finite element program and applied to the pressure time history, creating a moment time history. It was also determined the applied moment for a strong category five was greater than the cracking moment of the 16" girder, therefore, recommended the top floor not be used under that scenario.

Complete cladding analysis was also conducted, which included window analysis using ASTM E 1300, ASTM E 1886, and 1996 to determine the vulnerability of the windows due to high pressures and wind-borne debris. The ASTM E 1300 results revealed the design pressures for a 40 year old window should be +/-40 psf for a failure rate of eight per thousand and a pressure of +/- 50 psf for a failure rate of fifty per thousand. It was also determined that during the design and construction of the hospital the windows were designed and site tested for 40 psf.

Summarizing, the following are cladding areas determined throughout this report to have high hazards: 1st floor windows and windows that are adjacent to roofs with gravel have a high potential of breaking, and 8th floor windows expected to have above 80 psf in a category 3 and over 100 psf in a category 4 and 5 hurricane.

From the mechanical analysis it was determined the back-up generators and control panels would not work once flood waters rose above the 1st floor slab elevation.

The wind tunnel, structural, cladding, and mechanical analysis were compiled to develop the Shelter Report which consists of three Flood and two Wind sheltering plans. These plans include a flip chart, allowing the hospital to choose correct sheltering plan based on the given hurricane scenario. Recommendations and mitigation strategies were based on shelter report determination of high hazard areas. A list of available types of hurricane protection was compiled after consulting with contractors and manufactures in order to offer the hospital a variety of options for upgrading the hospital for better use as a hurricane shelter.

With this project being the first to use LSU's boundary layer wind tunnel, the wind tunnel's validation was included. A 1:50 model of Texas Tech field building pressure results were compared to studies completed by Cochran (1992) on the same type of model with the same flow conditions. In order to match Cochran's pressures the proper flow conditions were successfully achieved using velocity profile, turbulence intensity, and longitudinal length scale. For accuracy, dynamic calibration of the tubing was completed resulting in a dynamic corrector factor and two restrictors per tube used, and pressure transducer calibrated every day and zero reading taken prior and after every test. Additionally, peak and mean pressures coefficients were tested every 15° and the results successfully compared to Texas Tech full scale and Cochran's (1992) 1:50 models.

In the end, the adopted method linked a shelter's structural performance directly to the Saffir-Simpson hurricane scale, allowing emergency officials to have a better understanding on the performance of their shelter.

11.2 Recommendations for Future Research

With this being the first application of this method it would be advantageous if the method was applied to more buildings to gain more experience with the method. In the end, the proposed method will only work if it is accepted by either the engineering community or emergency officials that use it. Appling the presented method to more facilities and collecting information on how well it worked would allow for the method to be fine-tuned.

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APPENDIX A

LSU WIND TUNNEL DYNAMIC CALIBRATION (HEBERT, 2004)

A.1 Dynamic Calibration

Ideally, surface pressure measurements of a wind tunnel model would be made using pressure transducers with the pressure sensing diaphragms of those transducers mounted flush with the surface of the model. Space limitations and other considerations make this impractical. Surface pressures of wind tunnel models are typically measured using remotely located pressure transducers connected to the surface of the model with a length of small diameter tubing. This system of remotely located transducers introduces the need to correct the pressure signal data, as measured by a remotely located pressure transducer, to the actual pressure data at the surface of the model. The signal must be corrected due to the frequency response characteristics of the connecting tubing. The correction applied will be governed by the response characteristics of the entire system, but primarily by the response characteristics of the connecting tubing.

Surface pressures of a wind tunnel model are typically of a dynamic fluctuating nature. Pressure fluctuation will typically be occurring across a range of frequencies simultaneously and the response of the tubing system is frequency dependent. Pressure signals transmitted through the tubing may be amplified at some frequencies, while signal of other frequencies may be attenuated. A phase lag will also be introduced due to the distance the pressure signal must travel in the tubing. The angular phase lag is dependent not only on the frequency and tubing length, but also on the response characteristics of the tubing, and due to that response, the phase lag may be non-linear.

Accurate measuring of surface pressures require that a pressure transmitting tubing system be tuned for a uniform amplification of unity, or one, across the relevant frequency spectrum, or that the measured signal data be corrected numerically, based on the frequency response characteristics of the tubing. The LSU Boundary Layer Wind Tunnel employs both techniques for dynamic pressure signal correction. Restrictors, consisting of short lengths of tubing which have a smaller internal diameter than the principal tubing, are positioned in the pressure transmitting tubing. These restrictors have the effect of creating a nearly linear signal amplification ratio curve and phase lag curve across the relevant frequency spectrum. The restrictors also heavily attenuate high frequencies outside the relevant frequency range, this greatly reduces the problem of aliasing, where pressure fluctuations of higher frequencies than the relevant range may affect lower frequency signal measurements. This system has been tested by using a known signal input at one end of the tubing while collecting the signal with a pressure transducer identical to those that will be used in actual model testing. The measured data has been compared to the known signal and amplification ratios and phase lags have been calculated throughout the relevant frequency range.

A.2 Dynamic calibration curves

The amplification ratio curves shown below are for identical transducers measuring a signal through various pressure transmitting tubing systems

(Figure A.1). The short tube curve represents the amplification ratio at each frequency for a transducer mounted on as short a length of tubing as possible. The Normal setup curve is for a uniform length of tubing of a practical length for remote pressure sensing. The Restrictor curve is for the pressure transmitting tubing system currently employed by the LSU Boundary Layer Wind Tunnel.

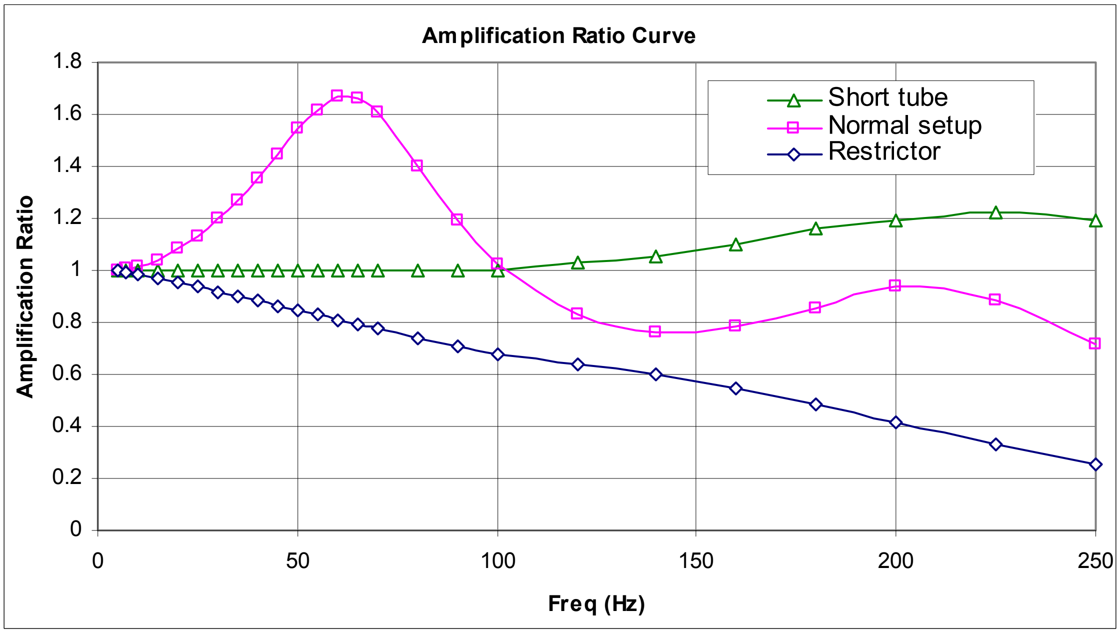

Figure A.1 – Amplification Ratio Curve

The Phase Lag curves shown below are for measuring a signal through the same Normal setup and Restrictor pressure transmitting tubing systems previously mentioned (Figure A.2).

A.3 Signal Correction

The amplification ratio and phase lag curves provide the information about the characteristics of the pressure measuring system necessary to apply a dynamic frequency response correction to the data collected from the remotely located pressure transducers. The collected signal is decomposed into frequency components by applying a Fourier Transform to the data. Corrections for amplitude and phase lag are then made across the frequency spectrum. The data is then recompiled using an Inverse Fourier Transform, which results in a signal that now represents actual conditions at the surface of the model.

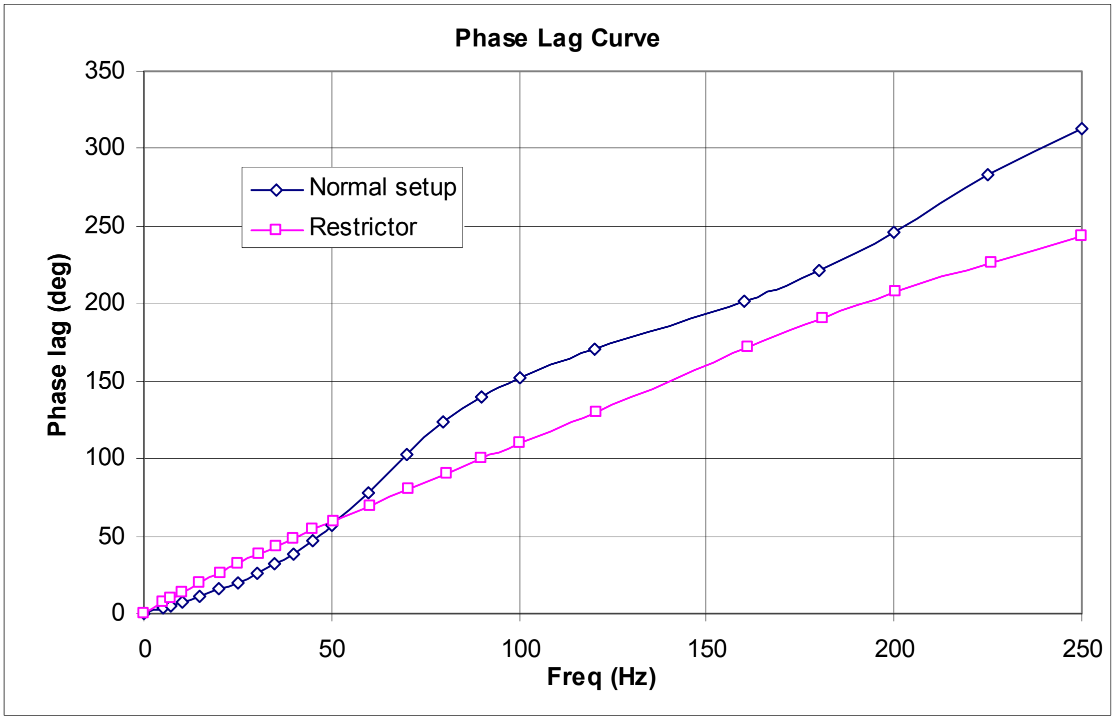

Figure A.2 - Phase Lag Curve

APPENDIX B

LSU WIND TUNNEL PRESSURE RESULTS FOR TEXAS TECH EXPERIMENT

Texas Tech Mean Pressure Coefficients

Angle	Chan 1, 2, & 3	Chan#4	Chan#5	Chan#6	Chan#7	Chan#8	Chan#9	Chan#10	Chan#11	Chan#12	Chan#13	Chan#14	Chan#15	Chan#16
Tap	Pitot Tubes	*11407*	*22304*	*31407*	*42204*	*42206*	*42306*	*50205*	*50209*	*50505*	*50509*	*50823*	*50905*	*50909*
0		0.75	-0.16	-0.19	-0.17	-0.17	-0.17	-0.13	-0.12	-0.12	-0.11	-0.18	-0.11	-0.11
15		0.69	0.00	-0.30	-0.41	-0.44	-0.45	-0.17	-0.17	-0.16	-0.14	-0.24	-0.16	-0.13
30		0.59	0.19	-0.38	-0.50	-0.63	-0.61	-0.22	-0.24	-0.23	-0.22	-0.20	-0.23	-0.20
45		0.38	0.37	-0.40	-0.51	-0.65	-0.63	-0.26	-0.28	-0.25	-0.24	-0.27	-0.25	-0.22
60		0.15	0.48	-0.53	-0.41	-0.44	-0.42	-0.28	-0.28	-0.35	-0.30	-0.25	-0.41	-0.38
75		-0.05	0.51	-0.72	-0.23	-0.25	-0.23	-0.31	-0.29	-0.36	-0.33	-0.25	-0.42	-0.41
90		-0.51	0.51	-0.39	-0.18	-0.21	-0.19	-0.20	-0.20	-0.21	-0.21	-0.29	-0.24	-0.28
105		-0.75	0.52	-0.05	-0.25	-0.25	-0.24	4.98	-0.19	-0.21	-0.19	-0.29	-0.21	-0.21
120		-0.59	0.47	0.14	-0.37	-0.40	-0.38	6.29	-0.33	-0.47	-0.26	-0.26	-0.44	-0.26
135		-0.40	0.36	0.35	-0.50	-0.65	-0.61	6.29	-0.61	-0.95	-0.46	-0.28	-1.00	-0.30
150		-0.38	0.17	0.59	-0.50	-0.68	-0.62	6.29	-0.82	-0.95	-0.83	-0.22	-1.13	-0.72
165		-0.31	0.01	0.70	-0.42	-0.53	-0.47	6.30	-0.74	-0.91	-0.75	-0.19	-0.97	-0.81
180		-0.20	-0.14	0.73	-0.13	-0.15	-0.13	6.26	-0.58	-1.01	-0.64	-0.13	-1.01	-0.72
195		-0.31	-0.39	0.71	0.01	0.01	0.02	6.27	-0.40	-0.68	-0.27	-0.13	-1.24	-0.42
210		-0.38	-0.48	0.57	0.19	0.20	0.20	6.26	-1.06	-0.34	-0.26	-0.22	-0.46	-0.24
225		-0.42	-0.49	0.36	0.39	0.42	0.44	6.28	-1.76	-0.36	-0.30	-0.62	-0.28	-0.28
240		-0.60	-0.41	0.17	0.50	0.57	0.58	6.27	-1.89	-0.38	-0.79	-1.02	-0.30	-0.26
255		-0.73	-0.28	-0.04	0.51	0.59	0.60	6.26	-1.56	-0.94	-1.46	-1.05	-0.31	-0.49
270		-0.39	-0.24	-0.56	0.56	0.66	0.68	6.26	-1.27	-1.27	-1.24	-1.09	-0.84	-0.94
285		-0.06	-0.28	-0.80	0.58	0.66	0.69	6.27	-1.11	-1.08	-1.09	-1.14	-0.89	-0.95
300		0.10	-0.39	-0.62	0.49	0.53	0.55	6.28	-0.90	-0.79	-0.85	-0.96	-0.69	-0.75
315		0.37	-0.51	-0.40	0.35	0.35	0.38	6.28	-0.71	-0.58	-0.70	-0.53	-0.52	-0.56
330		0.57	-0.53	-0.37	0.18	0.16	0.20	6.29	-0.59	-0.49	-0.56	-0.22	-0.35	-0.33
345		0.70	-0.49	-0.31	0.02	0.00	0.04	6.29	-0.35	-0.26	-0.25	-0.15	-0.17	-0.17

Texas Tech Positive Peak Pressure Coefficients

Angle	Chan# 1, 2, & 3	Chan#4	Chan#5	Chan#6	Chan#7	Chan#8	Chan#9	Chan#10	Chan#11	Chan#12	Chan#13	Chan#14	Chan#15	Chan#16
Tap		*11407*	*22304*	*31407*	*42204*	*42206*	*42306*	*50205*	*50209*	*50505*	*50509*	*50823*	*50905*	*50909*
0		2.01	0.61	0.30	0.54	0.53	0.59	0.25	0.54	0.45	0.53	0.69	0.57	0.62
15		1.92	0.54	0.18	0.34	0.29	0.31	0.19	0.52	0.47	0.46	0.64	0.40	0.46
30		1.86	0.86	0.12	0.14	-0.03	0.01	0.16	0.26	0.25	0.27	0.43	0.24	0.26
45		1.44	1.26	0.12	0.11	-0.07	-0.05	0.13	0.25	0.32	0.28	0.19	0.41	0.41
60		1.06	1.49	0.05	0.19	0.11	0.13	0.14	0.40	0.45	0.47	0.42	0.36	0.46
75		0.63	1.56	-0.04	0.24	0.23	0.25	0.10	0.42	0.48	0.53	0.63	0.43	0.46
90		0.58	1.53	0.60	0.28	0.28	0.30	0.17	0.51	0.57	0.56	0.63	0.56	0.68
105		0.01	1.44	0.60	0.18	0.17	0.20	6.82	0.27	0.26	0.30	0.52	0.30	0.34
120		-0.04	1.34	0.92	0.12	0.09	0.12	6.48	0.20	0.26	0.24	0.33	0.27	0.24
135		0.12	1.09	1.34	0.14	-0.12	-0.02	6.47	0.16	0.15	0.35	0.19	0.15	0.37
150		0.11	0.87	1.83	0.10	-0.02	0.07	6.47	0.14	-0.01	0.19	0.34	-0.02	0.39
165	**Pitot Tubes**	0.18	0.51	1.97	0.25	0.29	0.29	6.46	0.37	0.20	0.36	0.58	0.12	0.40
180		0.26	0.55	2.06	0.56	0.55	0.61	6.43	0.62	0.37	0.61	0.64	0.21	0.55
195		0.17	0.29	1.88	0.60	0.63	0.63	6.44	0.43	0.44	0.38	0.39	0.20	0.49
210		0.09	0.18	1.82	0.91	1.04	1.07	6.43	0.27	0.39	0.43	0.46	0.54	0.51
225		0.16	0.16	1.50	1.21	1.34	1.36	6.45	0.05	0.25	0.54	0.58	0.43	0.24
240		-0.01	0.11	0.98	1.40	1.67	1.70	6.47	-0.34	0.50	0.58	0.27	0.21	0.53
255		0.21	0.25	0.64	1.50	1.86	1.87	6.46	-0.33	0.43	0.17	0.32	0.53	0.57
270		0.66	0.26	0.71	1.61	1.93	2.03	6.45	-0.03	0.13	0.15	0.34	0.43	0.43
285		0.65	0.19	0.03	1.57	1.84	1.87	6.45	-0.11	0.12	0.00	0.14	0.13	0.34
300		0.97	0.17	0.01	1.60	1.80	1.85	6.47	0.08	0.28	0.21	0.24	0.28	0.39
315		1.33	0.09	0.11	1.22	1.34	1.40	6.47	0.17	0.34	0.17	0.43	0.32	0.33
330		1.79	0.07	0.17	0.85	0.94	1.05	6.47	0.16	0.27	0.21	0.49	0.30	0.40
345		1.93	0.13	0.17	0.56	0.59	0.66	6.47	0.27	0.30	0.32	0.34	0.34	0.36

Texas Tech Negative Peak Pressure Coefficients

Angle	Chan 1, 2, & 3	Chan#4	Chan#5	Chan#6	Chan#7	Chan#8	Chan#9	Chan#10	Chan#11	Chan#12	Chan#13	Chan#14	Chan#15	Chan#16
Tap	Pitot Tubes	***11407***	***22304***	***31407***	***42204***	***42206***	***42306***	***50205***	***50209***	***50505***	***50509***	***50823***	***50905***	***50909***
0		-0.06	-0.99	-0.66	-1.08	-1.35	-1.26	-0.56	-1.27	-0.96	-0.91	-1.28	-0.80	-0.92
15		-0.09	-0.86	-0.74	-1.22	-1.22	-1.23	-0.51	-1.03	-0.91	-0.95	-1.54	-0.83	-0.84
30		-0.12	-0.37	-0.90	-1.20	-1.43	-1.41	-0.62	-0.77	-0.71	-0.72	-0.77	-0.75	-0.71
45		-0.30	-0.23	-0.96	-1.15	-1.26	-1.25	-0.66	-0.80	-0.90	-0.88	-0.78	-1.09	-1.03
60		-0.65	-0.16	-1.28	-1.13	-1.14	-1.12	-0.75	-1.11	-1.26	-1.22	-1.05	-1.46	-1.37
75		-1.11	-0.24	-1.64	-0.71	-0.74	-0.71	-0.75	-1.16	-1.58	-1.27	-1.49	-1.45	-1.54
90		-1.60	-0.35	-1.68	-0.73	-0.76	-0.74	-0.71	-1.20	-1.27	-1.18	-1.32	-1.31	-1.49
105		-1.57	-0.17	-1.07	-0.73	-0.74	-0.72	1.47	-0.75	-1.05	-0.78	-1.44	-1.11	-0.86
120		-1.32	-0.13	-0.57	-0.83	-0.89	-0.88	6.11	-1.20	-1.89	-1.09	-0.96	-1.83	-0.83
135		-0.93	-0.18	-0.30	-1.09	-1.23	-1.22	6.12	-1.85	-2.55	-2.00	-0.75	-2.65	-1.93
150		-0.89	-0.36	-0.17	-1.13	-1.40	-1.33	6.12	-2.06	-2.48	-2.36	-0.74	-2.74	-2.27
165		-0.80	-0.64	-0.12	-1.09	-1.32	-1.29	6.13	-2.44	-2.66	-2.30	-1.24	-2.78	-2.39
180		-0.69	-0.82	-0.12	-1.00	-1.17	-1.09	6.08	-2.52	-2.91	-2.39	-1.00	-2.96	-2.30
195		-0.84	-1.07	-0.10	-0.60	-0.66	-0.70	6.10	-1.99	-2.65	-1.52	-0.69	-2.76	-1.98
210		-0.90	-1.14	-0.22	-0.37	-0.40	-0.44	6.08	-3.14	-1.65	-1.15	-1.64	-2.89	-1.01
225		-0.97	-1.17	-0.38	-0.23	-0.26	-0.24	6.09	-3.95	-1.06	-2.74	-2.27	-1.84	-0.80
240		-1.32	-1.01	-0.66	-0.14	-0.19	-0.21	6.07	-4.30	-3.22	-3.74	-2.60	-0.96	-1.73
255		-1.59	-0.76	-1.17	-0.37	-0.40	-0.33	6.06	-3.57	-3.13	-3.48	-3.01	-1.91	-2.43
270		-1.61	-0.72	-1.95	-0.17	-0.21	-0.25	6.08	-3.71	-3.25	-3.22	-3.02	-2.53	-2.64
285		-1.12	-0.68	-1.64	-0.08	-0.09	-0.05	6.09	-3.65	-2.87	-3.00	-2.99	-2.28	-2.91
300		-0.65	-0.93	-1.26	-0.18	-0.24	-0.21	6.10	-3.21	-2.66	-2.56	-2.71	-2.05	-2.17
315		-0.33	-1.19	-0.96	-0.25	-0.31	-0.28	6.10	-2.60	-2.19	-2.09	-2.35	-1.65	-1.94
330		-0.19	-1.15	-0.83	-0.36	-0.42	-0.39	6.11	-1.92	-1.74	-1.85	-1.74	-1.36	-1.47
345		-0.11	-1.17	-0.80	-0.66	-0.68	-0.64	6.12	-1.57	-1.28	-1.42	-0.76	-0.85	-0.89

Texas Tech RMS Pressures

Angle	Chan 1, 2, & 3	Chan#4	Chan#5	Chan#6	Chan#7	Chan#8	Chan#9	Chan#10	Chan#11	Chan#12	Chan#13	Chan#14	Chan#15	Chan#16
Tap		***11407***	***22304***	***31407***	***42204***	***42206***	***42306***	***50205***	***50209***	***50505***	***50509***	***50823***	***50905***	***50909***
0		0.29	0.19	0.14	0.19	0.20	0.21	0.12	0.17	0.16	0.17	0.22	0.16	0.17
15		0.27	0.15	0.14	0.18	0.21	0.20	0.11	0.17	0.15	0.16	0.21	0.15	0.15
30		0.26	0.17	0.15	0.18	0.19	0.19	0.11	0.15	0.14	0.14	0.15	0.14	0.14
45		0.24	0.20	0.15	0.17	0.18	0.18	0.12	0.15	0.16	0.15	0.14	0.17	0.16
60		0.20	0.22	0.18	0.16	0.17	0.17	0.13	0.18	0.21	0.20	0.16	0.22	0.22
75		0.20	0.23	0.20	0.14	0.14	0.14	0.13	0.20	0.22	0.22	0.21	0.23	0.24
90		0.29	0.24	0.28	0.15	0.15	0.15	0.12	0.19	0.19	0.20	0.24	0.20	0.23
105		0.20	0.23	0.19	0.14	0.14	0.14	2.57	0.14	0.15	0.14	0.22	0.15	0.15
120		0.17	0.21	0.19	0.15	0.15	0.15	0.05	0.16	0.27	0.15	0.15	0.30	0.14
135		0.15	0.19	0.23	0.17	0.17	0.17	0.05	0.28	0.33	0.29	0.14	0.42	0.23
150		0.15	0.17	0.27	0.17	0.18	0.19	0.05	0.26	0.28	0.31	0.15	0.31	0.38
165	**Pitot Tubes**	0.14	0.16	0.29	0.18	0.21	0.21	0.05	0.29	0.32	0.29	0.20	0.31	0.31
180		0.14	0.18	0.30	0.18	0.20	0.19	0.05	0.32	0.36	0.32	0.20	0.36	0.34
195		0.15	0.18	0.28	0.15	0.16	0.16	0.05	0.31	0.42	0.20	0.15	0.40	0.32
210		0.15	0.18	0.26	0.17	0.18	0.19	0.06	0.56	0.18	0.15	0.22	0.45	0.16
225		0.16	0.18	0.24	0.21	0.23	0.24	0.06	0.47	0.16	0.30	0.42	0.18	0.15
240		0.18	0.16	0.20	0.22	0.26	0.26	0.07	0.51	0.29	0.64	0.36	0.16	0.20
255		0.21	0.15	0.21	0.22	0.27	0.27	0.06	0.39	0.55	0.46	0.36	0.22	0.37
270		0.29	0.14	0.30	0.24	0.29	0.29	0.06	0.36	0.39	0.39	0.39	0.34	0.37
285		0.20	0.14	0.21	0.22	0.26	0.27	0.05	0.33	0.34	0.34	0.34	0.29	0.32
300		0.19	0.15	0.18	0.22	0.26	0.26	0.05	0.32	0.31	0.30	0.37	0.26	0.28
315		0.23	0.17	0.16	0.20	0.22	0.23	0.05	0.29	0.27	0.29	0.38	0.23	0.26
330		0.26	0.17	0.15	0.17	0.18	0.18	0.06	0.23	0.22	0.25	0.21	0.22	0.23
345		0.28	0.18	0.14	0.16	0.16	0.17	0.06	0.21	0.19	0.20	0.15	0.15	0.15

APPENDIX C

INDEPENDENT REVIEW OF TEXAS TECH AND WEST JEFFERSON WIND TUNNEL RESULTS

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March 10, 2004.

Dear Dr. Levitan,

Thank you for the opportunity to review some of the work done to date in the LSU Boundary-Layer Wind Tunnel. It is good to keep in touch with how wind-engineering research continues to penetrate into lowrise building design. As we discussed on the telephone it appears that your research group is on the right path to develop a useful facility; given the obvious constraints of a short fetch length in the current wind tunnel. I do not have much to add beyond our conference call, but here are a few notes that I made while reviewing the data package entitled "LSU Hurricane Center - Texas Tech and West Jefferson Hospital Experiments".

The Texas Tech Building:

The use of the well-studied TTU Building to assess the veracity of the LSU Boundary-Layer Wind Tunnel was a rational approach. The vertical mean velocity profile [Figure A1], developed to simulate the open-country approach flow associated with the full-scale Lubbock site, seems fine for the important three to five building heights above the ground plane. The vertical profile of longitudinal turbulence intensity [Figure A2] does not match the full-scale data or suggested profiles in the literature as well as one would hope; principally because of the lack of turbulent energy at the upper elevations. However, the longitudinal turbulence intensity near the roof height is in fair agreement (say, 16 versus 18 percent) with the full-scale and target values. Whilst the shortfall in turbulent energy above about one and a half roof heights higher that the ground plane is shortcoming (influences the momentum transfer through the boundary-layer thickness) it is probably not a major source of concern. Some effort to increase the upper-level, longitudinal turbulence may be a useful future research project to pursue (perhaps upper-level, horizontal, inclined vane pairs would help with boosting the TI and L_{ux}, as well). The longitudinal length scale (L_{ux}) is a notoriously difficult parameter to measure and/or define - even if the full-scale neutrality of the ambient wind is assured. It is usually discussed, or thought of, as a **range** of typical flow-wise eddy sizes within the flow. Even with this flexibility in mind, the value of L_{ux} in the LSU Boundary-Layer Wind Tunnel is substantially smaller than the full-scale data [Figure A3]. In the field the value of L_{ux} is several times larger than the largest dimension on the TTU Building (e.g., at roof height about 100 m in full scale). However in your wind tunnel it is about the same size as the largest dimension of the model (at roof height about 20 m in full scale). This observation is likely to influence separation curvature, reattachment and vortex formation/longevity. I suspect that a plot of model and full-scale longitudinal flow spectra would show a similar scale mismatch (i.e. model size versus flow characteristics).

To fully understand the atmospheric boundary-layer simulation in your wind tunnel it would be useful to measure the vertical profiles of transverse and vertical turbulence intensity along with the corresponding length scale (L_{uy} and L_{uz}). The target ratios of the three turbulence intensities and length scales may be found in a variety of sources from ESDU to Counihan [1975]. The transverse and vertical profiles of turbulence intensity are usually measured with a boundary-layer, cross-film anemometer (although some multi-hole pressure probes can now achieve the same goal) and the lateral and vertical length scales with a pair of progressively displaced single hot-film anemometers. Whilst on the topic of wind-tunnel assessment, some horizontal profiles of mean velocity will let you know the extent of the intrusion of the wall boundary layers into the data-collection region on the turntable. This knowledge will help you to decide on appropriate model extents to be used.

The pressure coefficient data presented showed generally good mean and peak agreement on the wall taps. However, the roof taps showed larger mean and peak pressure coefficients when compared to other published wind-tunnel data. It is likely that the length-scale mismatch is influencing the roof data (separation curvature, vortex formation, etc.) collected in the LSU 1:50 TTU Building study, since other investigators have been able to get good agreement

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between the wind tunnel and full scale for the TTU Building for *mean* pressure coefficients. Your *peak* roof pressure coefficients are also a bit larger than the reference values. It would be interesting to compare the your TTU roof peak pressure coefficients with the full-scale data, rather than my CSU data. Since my peak pressure coefficient results were too small under the vortex flows when compared to the TTU full-scale data and you may be closer to the full-scale data in this region. This might be an example of getting better results for the wrong reasons (i.e. the L_{ux} mismatch may be increasing your peak roof data). Anyway, focusing on the local peak pressures generated by your TTU Building comparison it seems that the general azimuth trends are correctly achieved and also some ultimate over-estimation of cladding pressures is likely to occur. This observation suggests that the West Jefferson Hospital data, collected in the same wind tunnel, may be useful; albeit somewhat conservative. Lastly, the reference velocity correction and dynamic tubing signal correction both seemed very thorough. I suspect that the latter is due to no small influence from Dr. John Holmes and your work on tubing dynamics would stand up to that used by many of the leading commercial wind-engineering laboratories.

The West Jefferson Hospital:

The vertical mean velocity profile for the study of this 1:200 model of a 33-m tall hospital agrees well with the target one of ASCE-7 Exposure B [Figure 8]. The vertical longitudinal turbulence intensity [Figure 9] falls within the suburban range suggested by Holmes [2001] for more than two building heights, and also agrees quite well with the Australian reference. I also checked these data against that recommended by ESDU and the agreement was fine for the same elevations above the ground plane. As noted in the TTU building study the longitudinal length scale in this suburban environment, over the height of the building, is less than needed [Figure 10]. In a longer, wider, commercial, wind tunnel we would have a suburban value of L_{ux} at this building height of about 600 to 800 mm (as suggested by the "target" in Figure 10), rather than the 300 to 350 mm in the LSU tunnel. This value is of the order of the size of the model and so is a scaling mismatch which may have a similar effect to that noticed in the TTU Building study, above. One could take the view, from the TTU Building data presented, that the length scale mismatch will result in correct (walls) or slightly conservative (roof) pressure data from the test.

An inspection of the magnitudes of the mean and peak pressure coefficients for the various taps in the "WJ Results" section seems reasonable when one adjusts for the reference Pitot tube height. The reference height in the LSU study is at the roof height (33 m in full scale), which is fine. However, the typical reference height used in the CPP facility would be in the upper portions of the boundary layer (say, 150 m in full scale). The lower LSU reference height means that the pressure coefficients will be larger, when compared to what I am used to seeing, due to the smaller magnitude of q in the denominator. The ratio of the LSU to CPP pressure coefficients would be:

$$\frac{C_{P(LSU)}}{C_{P(CPP)}} = \left[\left(\frac{150}{33}\right)^{0.23}\right]^2 = 2.0$$

Thus, in reviewing the pressure coefficient plots I would expect to see values about twice the size of those I might expect to see in a project done here at CPP. This is in no way a criticism. It simple allows me to calibrate my eye to the values presented. On this basis I can say that the magnitudes of the pressure coefficients presented do not seem unusual or out of the ordinary.

The next item to review was to see if the shapes of the pressure coefficient azimuth plots made physical sense. Using the tap drawings and the orientation plan provided, I inspected a several key taps. Incidently, I found the orientation plan with wind azimuths on it a bit confusing, since the directions appeared to be reversed from the conventional compass rose. Also, the north arrow seemed to point west. Anyway, by simply accepting the azimuths shown and comparing them to the pressure coefficient plots the azimuthal trends seemed reasonable. For example, tap 1A04 is low on a building corner and one might expect positive mean pressure coefficients when the wind comes from about 0 to 90 degrees. This is true. Also a large negative peak pressure coefficient at about 135 degrees would suggest separation around the corner. Tap 8A14 exhibits similar trends, but with larger magnitudes as one might expect since it is higher on the building. Tap 0D01 is a roof corner tap with a large negative peak for southerly winds that seemed quite reasonable. Flow visualization may show a vortex on the roof at this azimuth. Similar observations were made at other taps (such as 0A03, 0A04, 00K01, 8C01, 8C01 and 8A01) and the plots seemed reasonable over the range of azimuths. The repeatability checks were a useful quality assurance check. They were all fine except tap 8A15 which exhibited a strange variation at 120 degrees (also tap 8C02 at 300 degrees). These results may come from your choice of methodology to generate the peak pressure (average of five ergodic experiments, up-crossing, best linear unbiased estimator, etc.), or it could be as simple a physical change in the model at 120 (or 300) degrees that was not in both experiments. Perhaps these taps should be retested once again to see which repeats. Some investigation here?

The comparison of pressure coefficients with and without the surrounding area model present showed the impact of the nearby buildings. The trends were not out of the ordinary and such an investigation can be illustrative to explain some mechanisms to students, or perhaps, a client.

The frame load coefficients were presented as mean values and could be slightly conservative, as illustrated by the TTU study. To be useful to the structural engineer a gust factor, measured or estimated, needs to be applied. With enough pressure transducers the simultaneous pressures over the building frame (or just a portal frame) could be measured directly, and so incorporate the degree of pressure correlation over the structure. With the length scale mismatch in the approach flow this may require some additional thought and research. A smaller length scale than required may result in less peak pressure correlation over the building surface than really exists in the full-scale where the building is more likely to be fully engulfed in a passing turbulent eddy for a longer period of time. Just a thought.

Lastly, the raw data appear reasonable for their intended purpose. However, a structural engineer will want far more data reduction before using these results. The coefficients need to be broken down 50 or 100-year cladding pressures over the surface of the building (say as contours). Then cladding zone diagrams (rectangular blocks of design pressures that follow the architectural features) can be developed, with internal pressures included, to yield net pressures across the facade. Similarly the presentation of structural loads needs to be presented as 50 or 100-year moments and/or shears with the critical design cases (load combinations and critical wind azimuths) easily seen. It is more conventional to collect data at 10 degree increments (36 directions), rather than 15 degree increment (24 directions). In future projects the tap numbering scheme could be simpler. For example, use a sequence of numbers like: roof taps (101, 102,...), north wall taps (201, 202,...), west wall (301, 302,...), south wall (401, 402,...) and east wall (501, 502,...). Just a suggestion. I trust these are the sorts of observations that you wanted as part of your quality assurance program. Please feel free to call if anything is unclear.

Yours sincerely,

Dr. Leighton Cochran, M.ASCE, MIEAust, CPEng

Enclosures
p.c. File

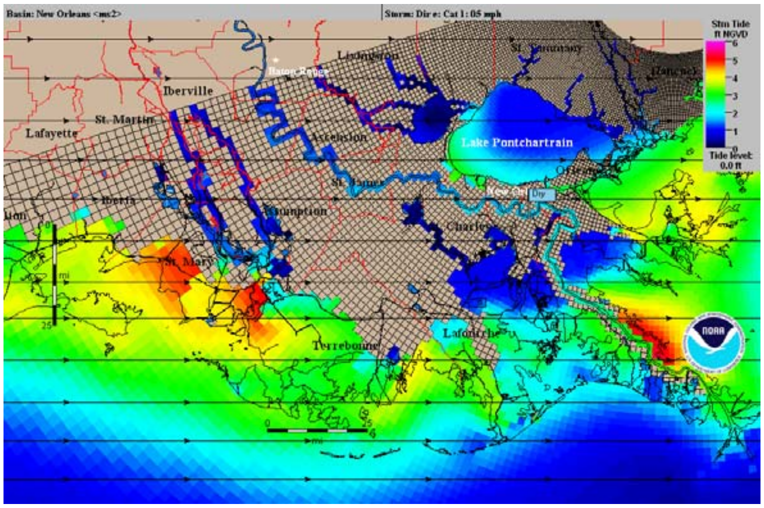
Filename = "Levitan-101.wpd"

APPENDIX D

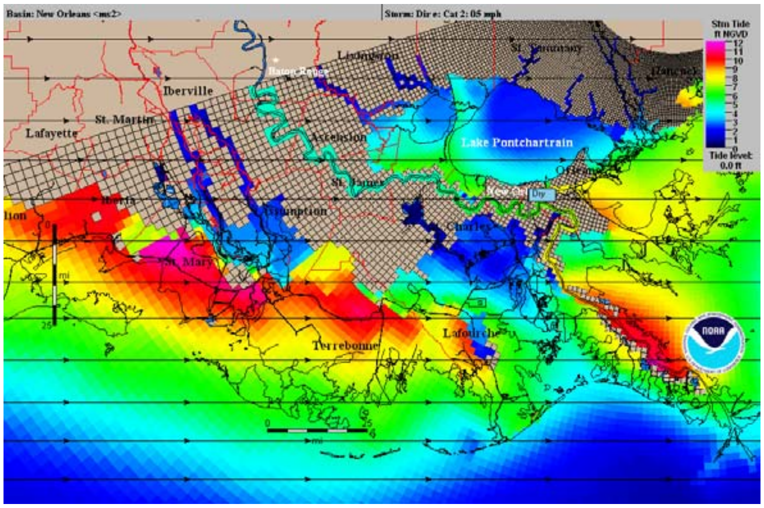
SLOSH RESULTS

Direction: East

Forward Speed: 5 mph



Category 1



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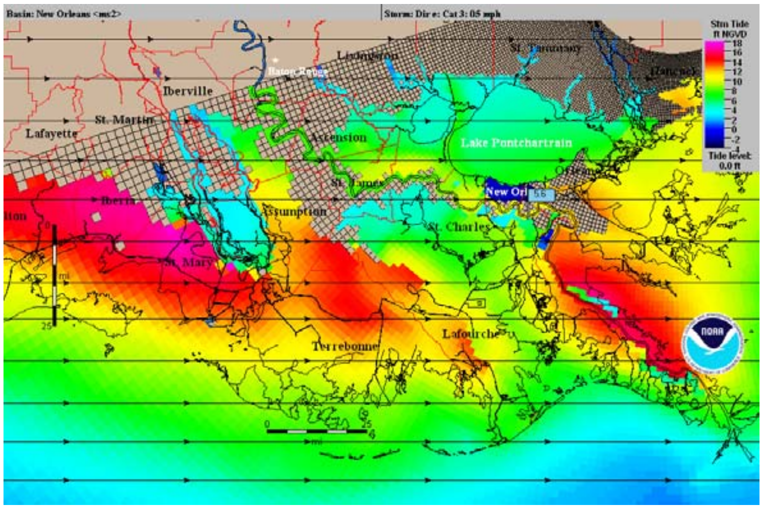

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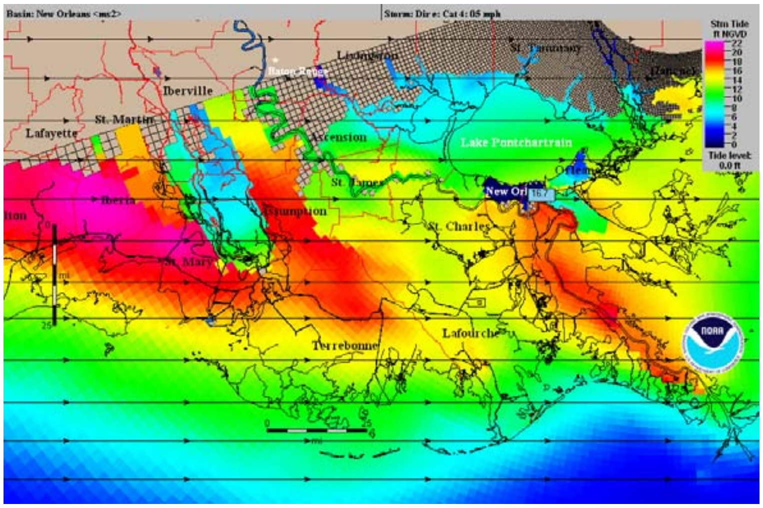

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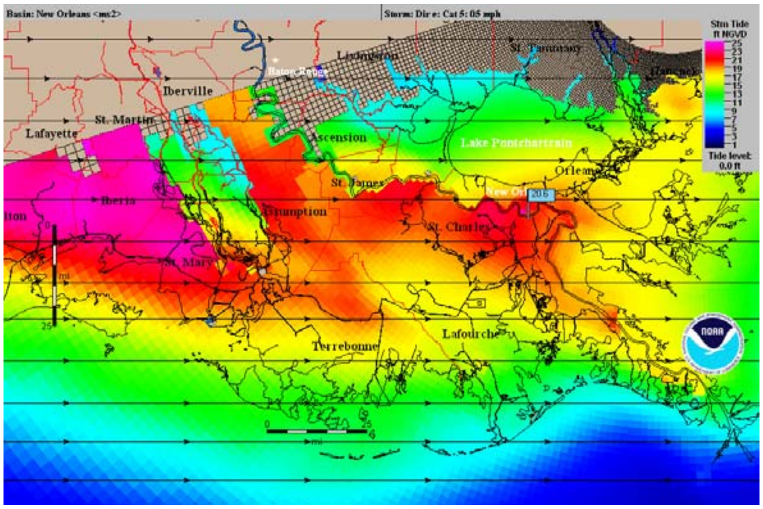
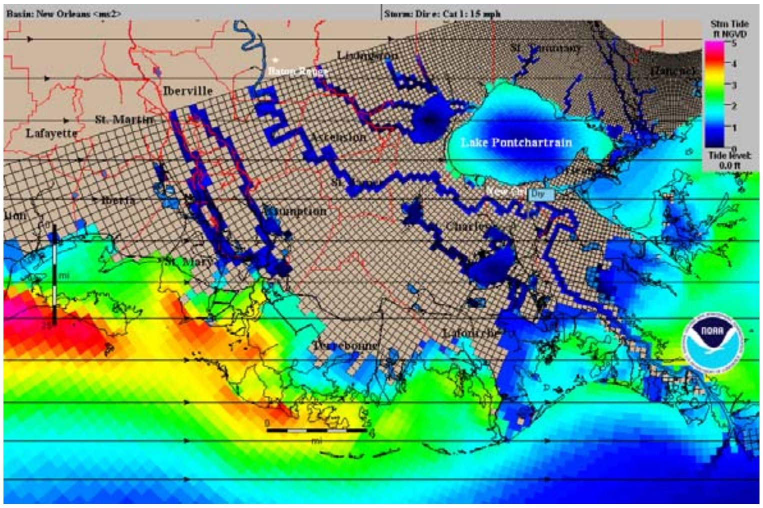
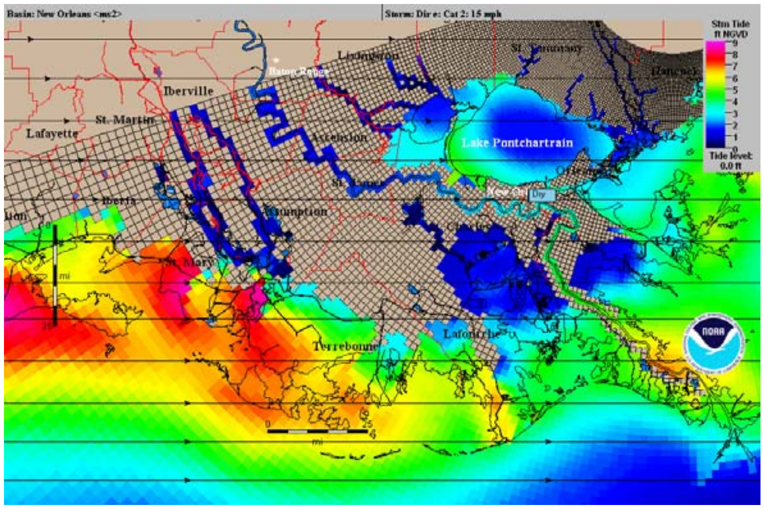


Category 5

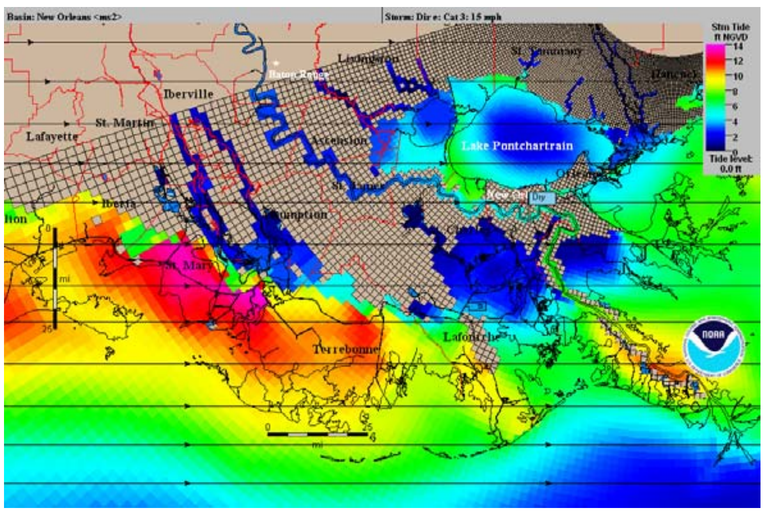
Forward Speed: 15 mph



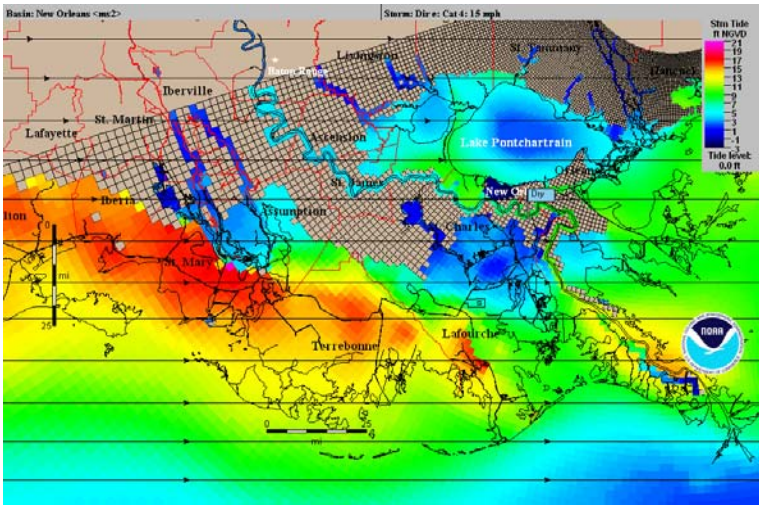
Category 1



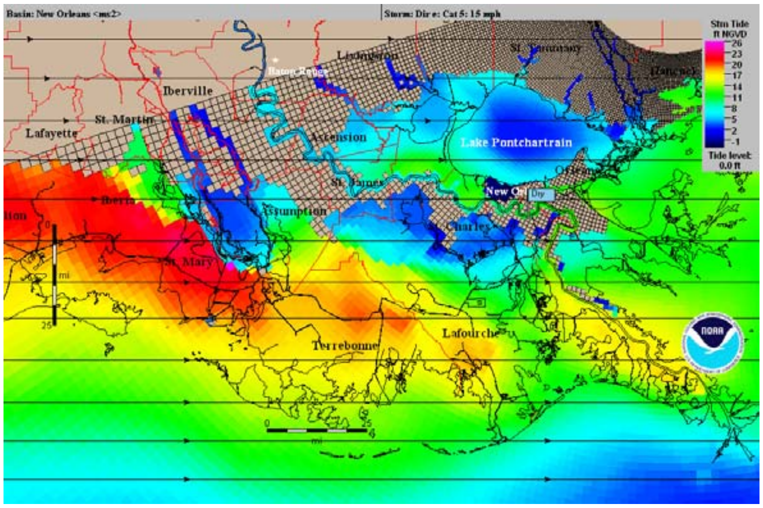
Category 2



Category 3



Category 4

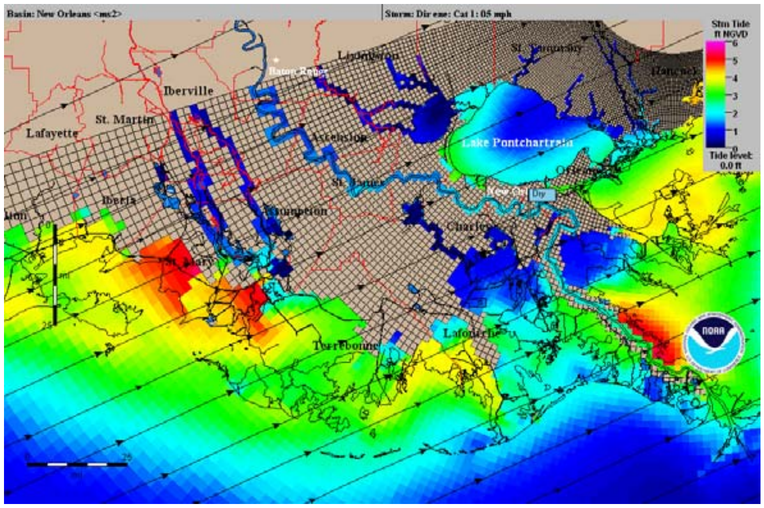


Category 5

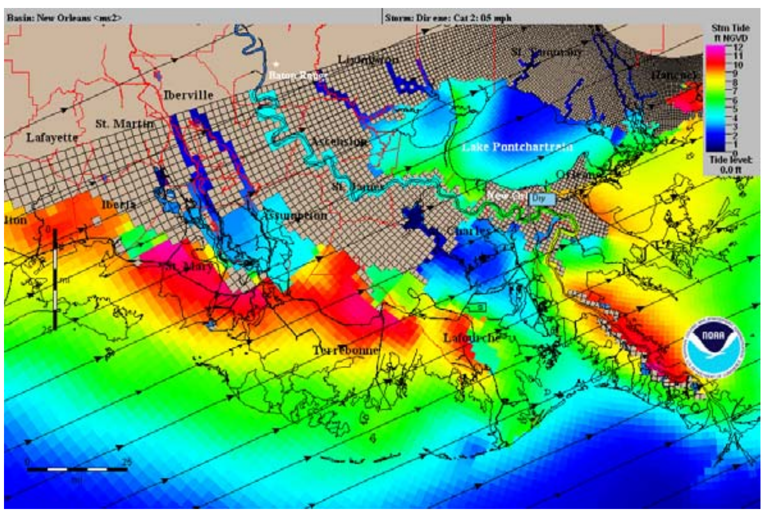
Direction: East North East

Forward Speed: 5 mph

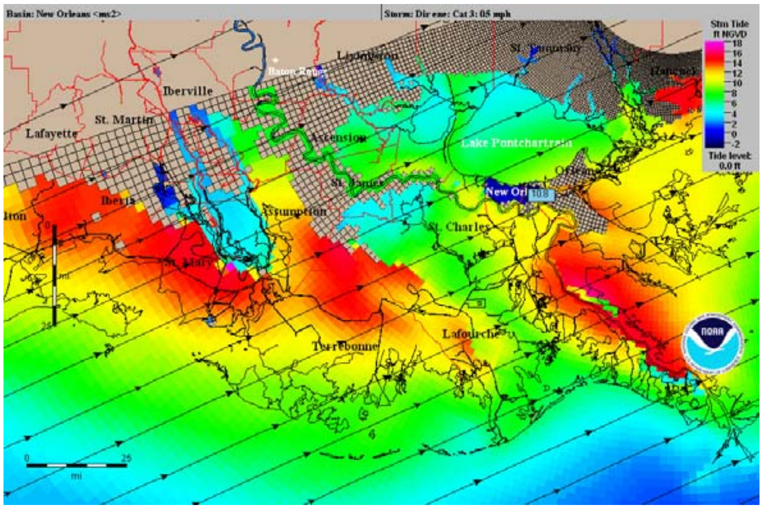
Mean Tide



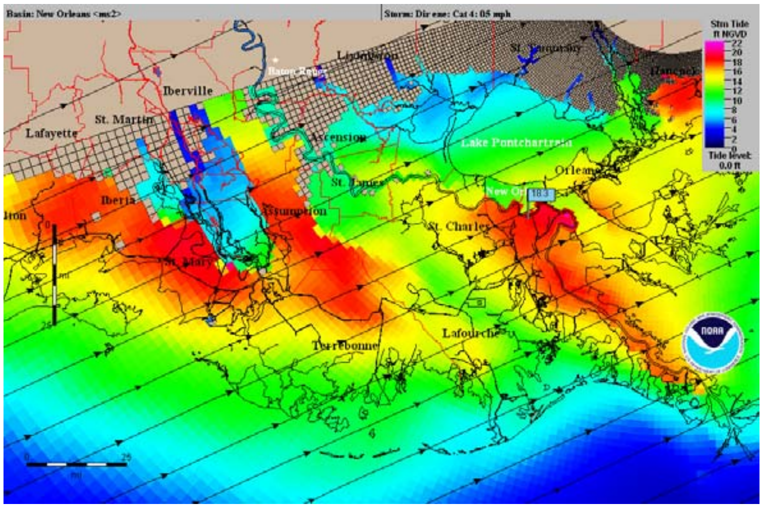
Category 1



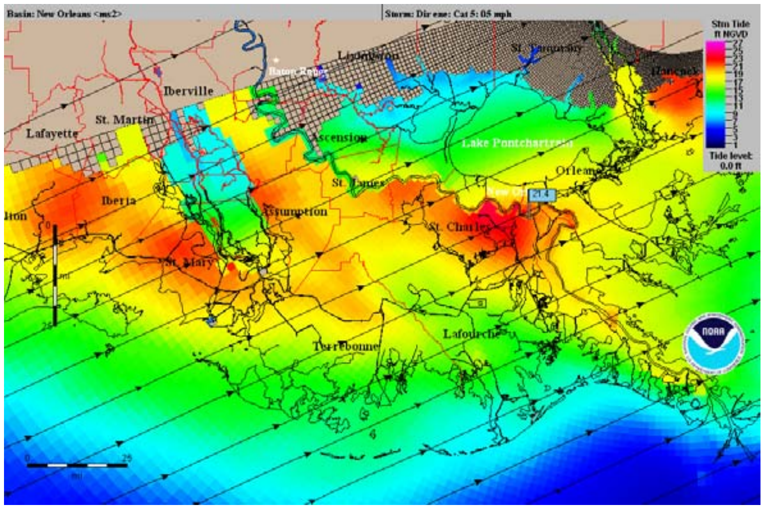
Category 2



Category 3

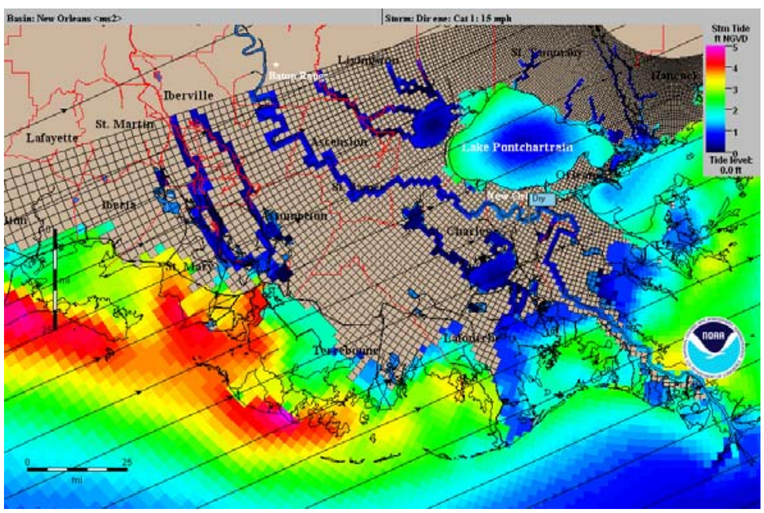


Category 4

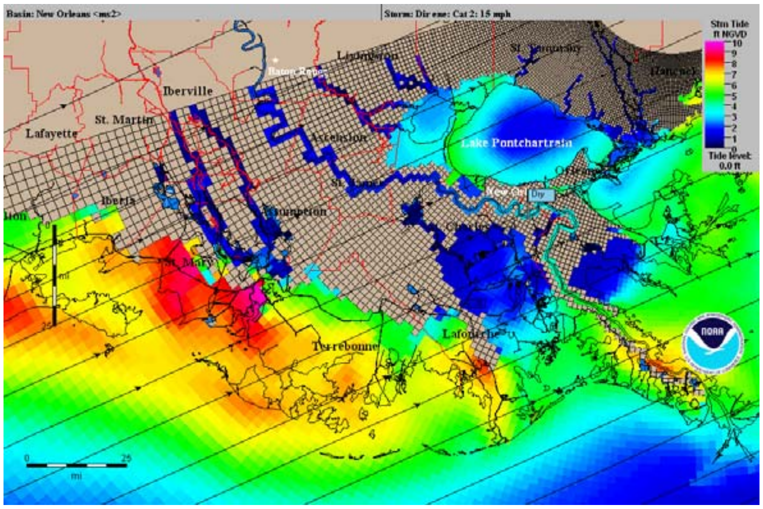


Category 5

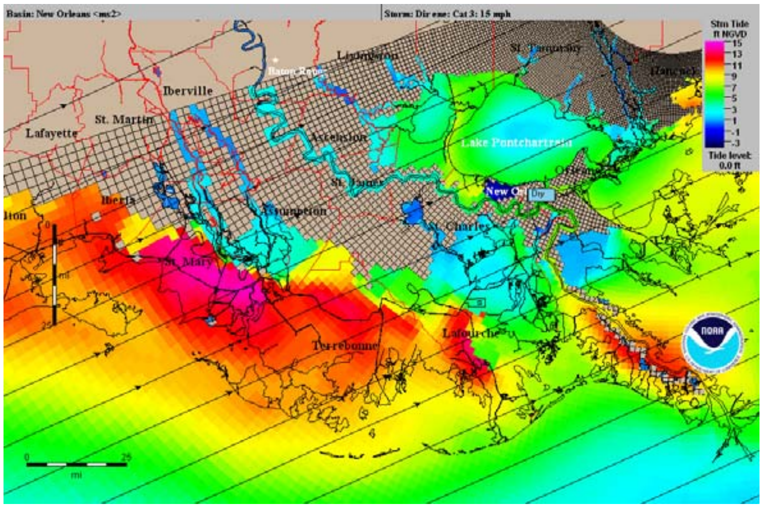
Forward Speed: 15 mph



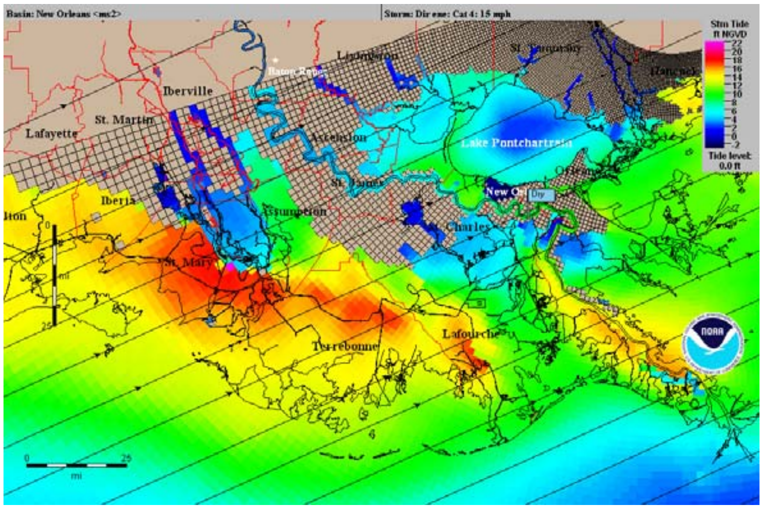
Category 1



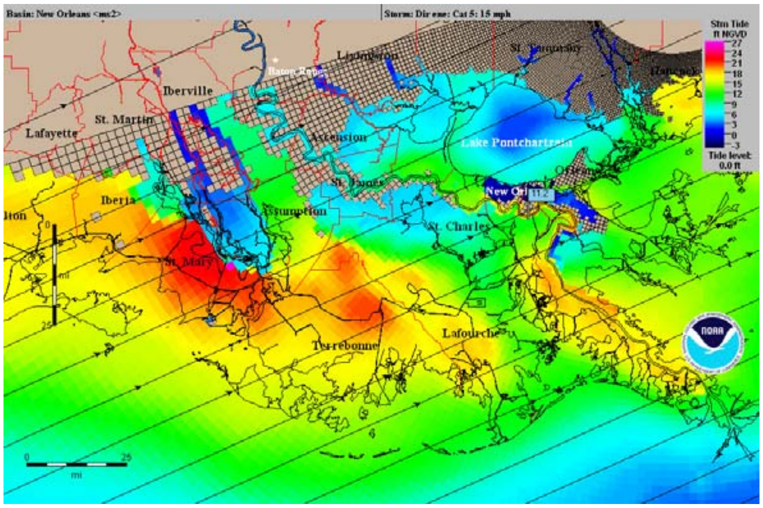
Category 2



Category 3



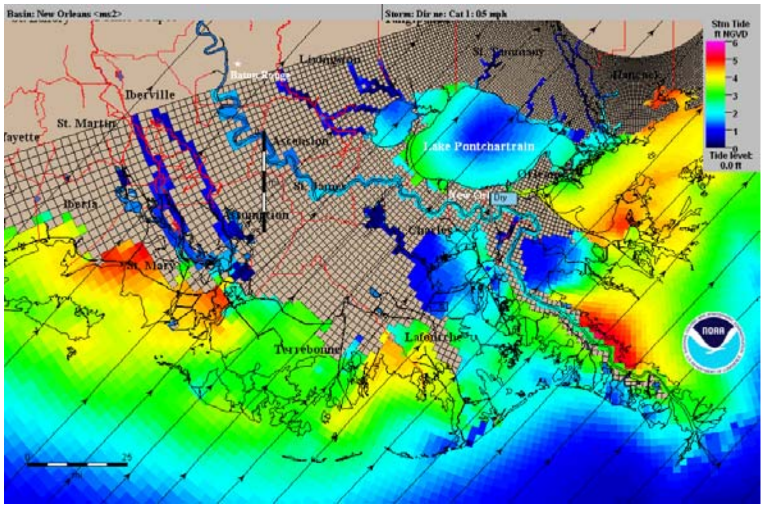
Category 4



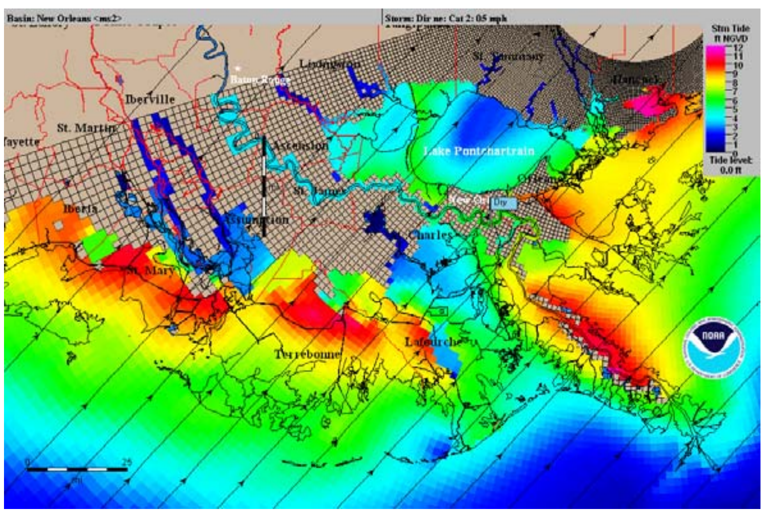
Category 5

Direction: Northeast

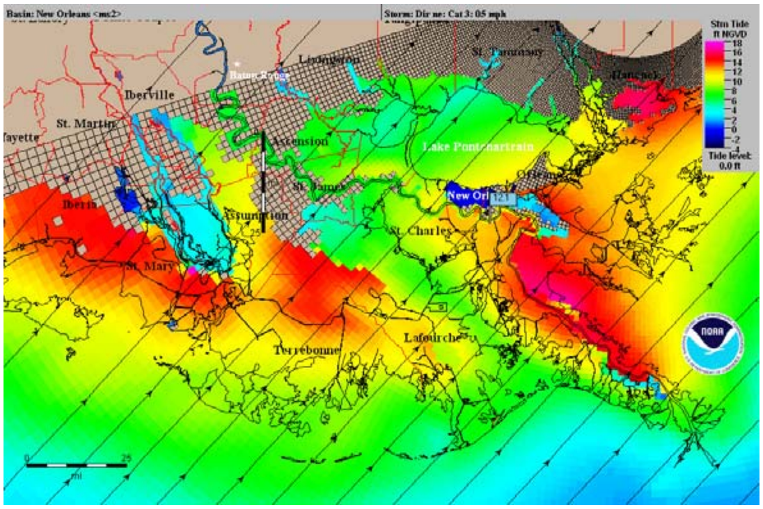
Forward Speed: 5 mph



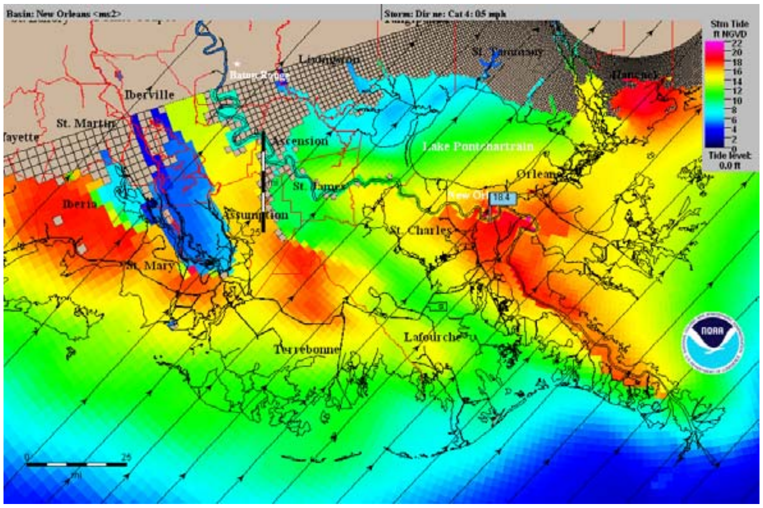
Category 1



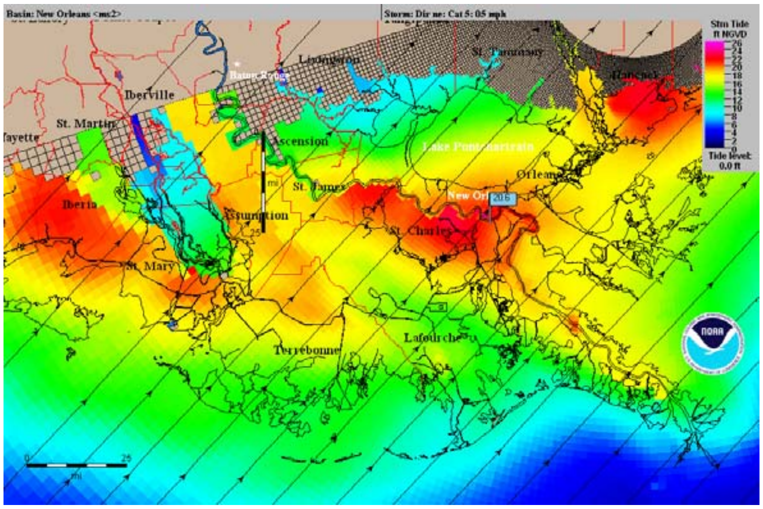
Category 2



Category 3

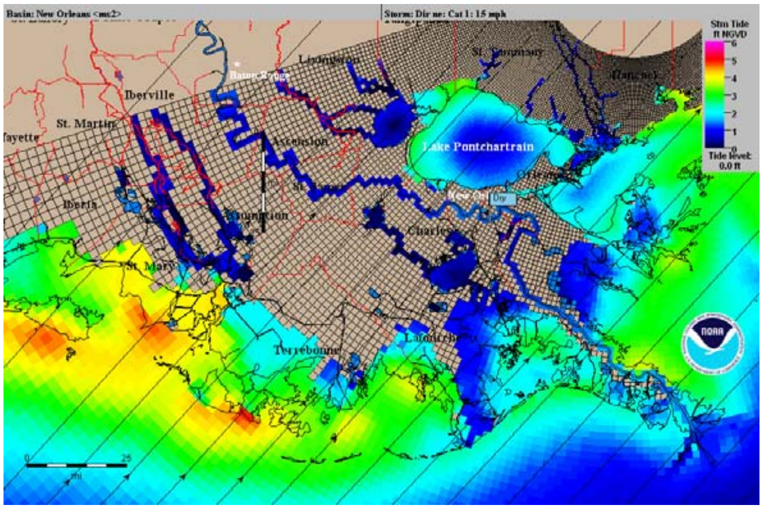


Category 4

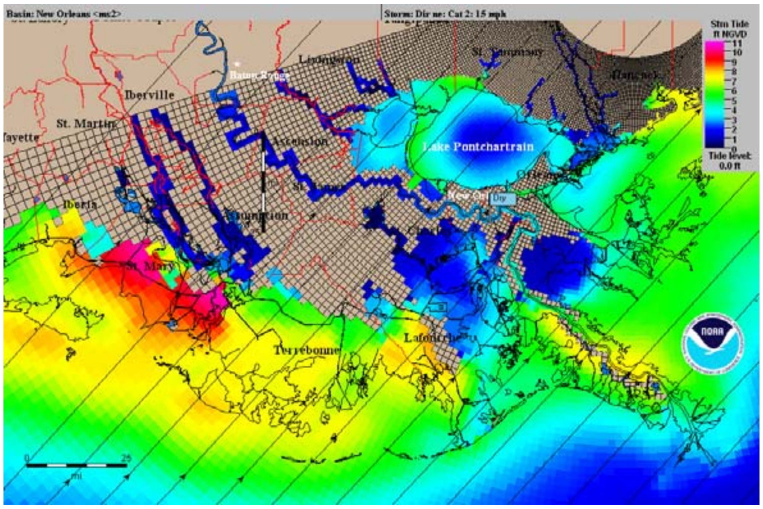


Category 5

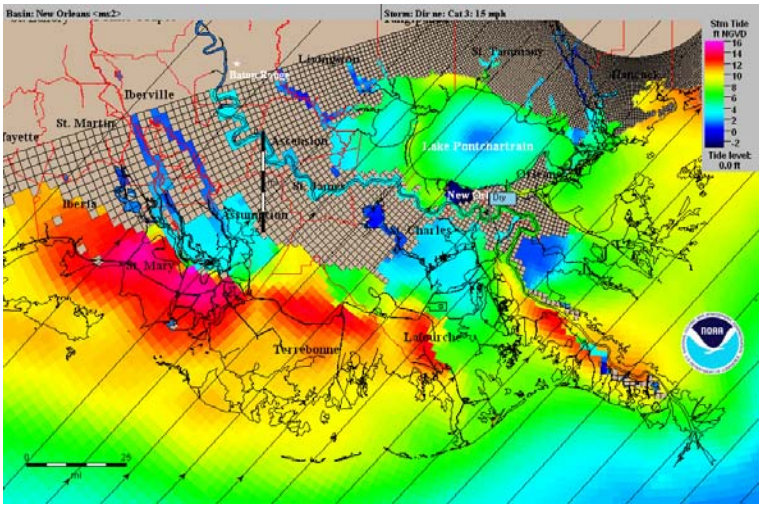
Forward Speed: 15 mph



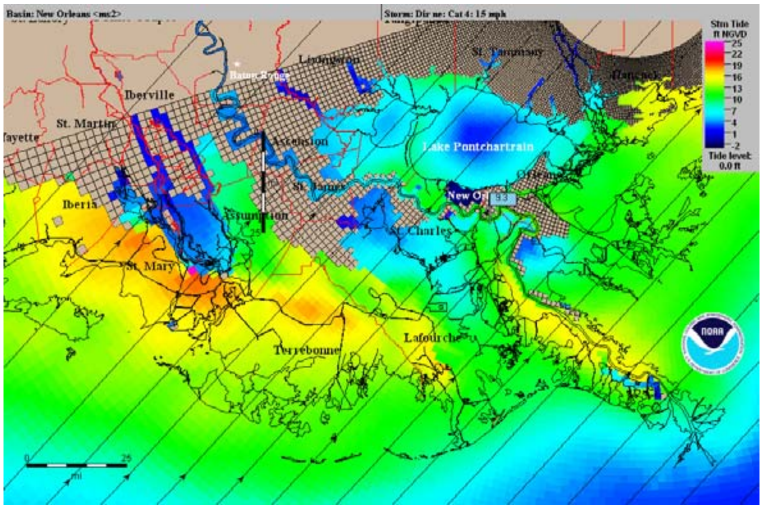
Category 1



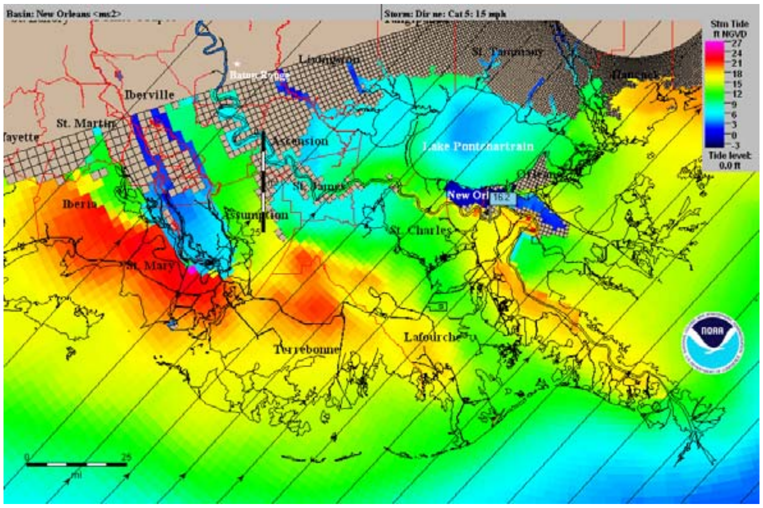
Category 2



Category 3



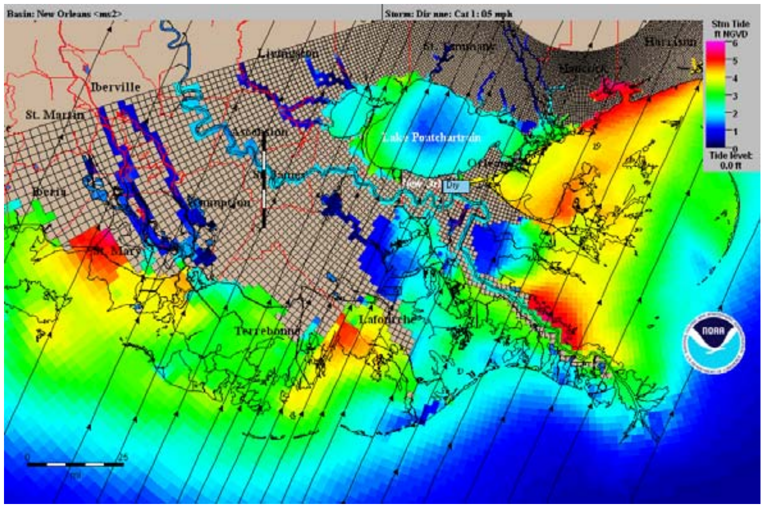
Category 4



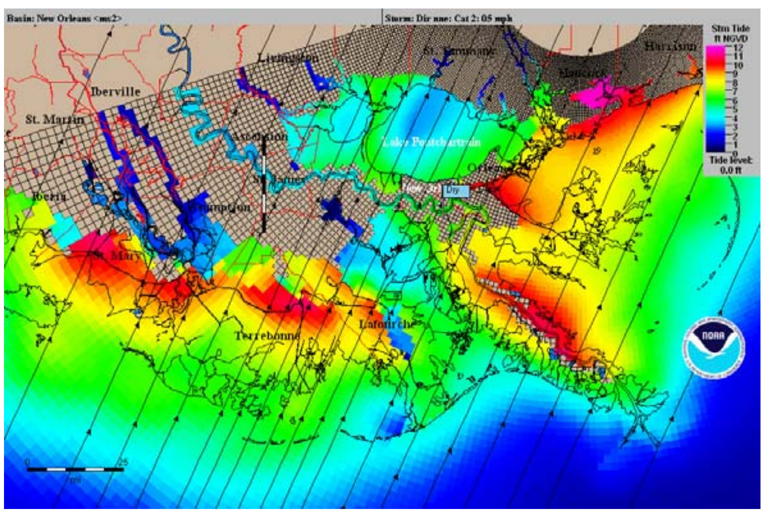
Category 5

Direction: North Northeast

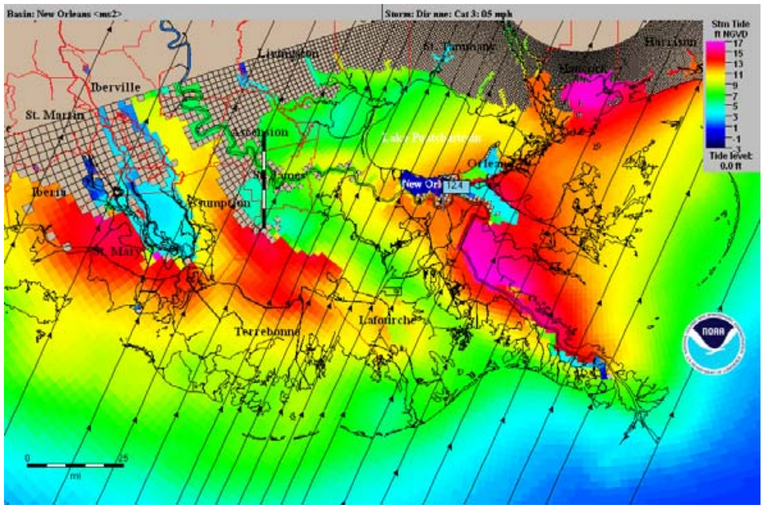
Forward Speed: 5 mph



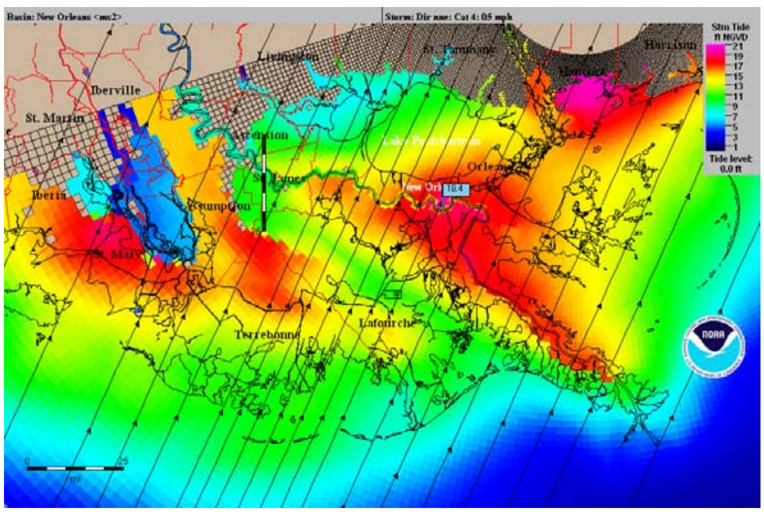
Category 1



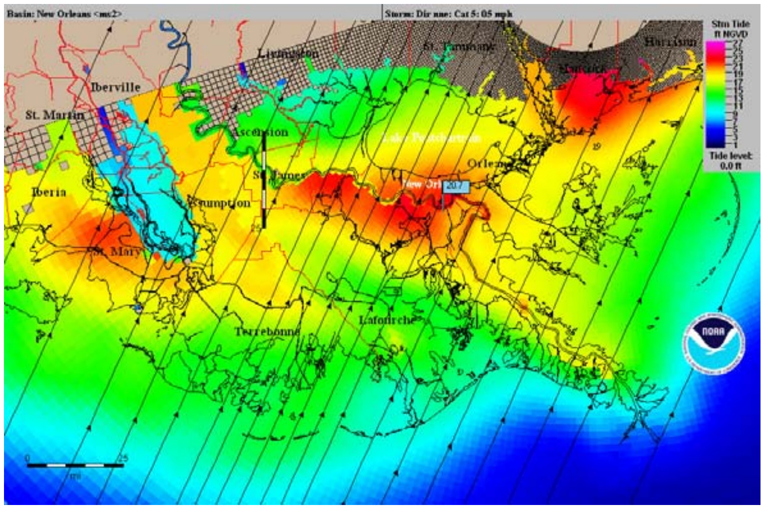
Category 2



Category 3

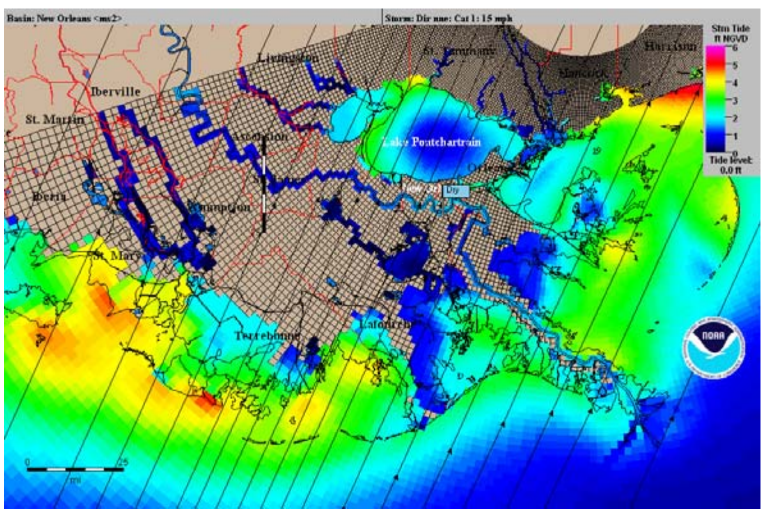


Category 4

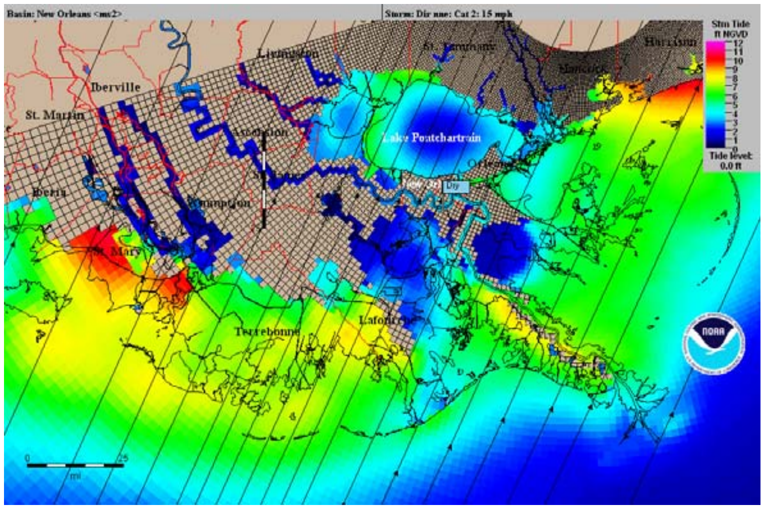


Category 5

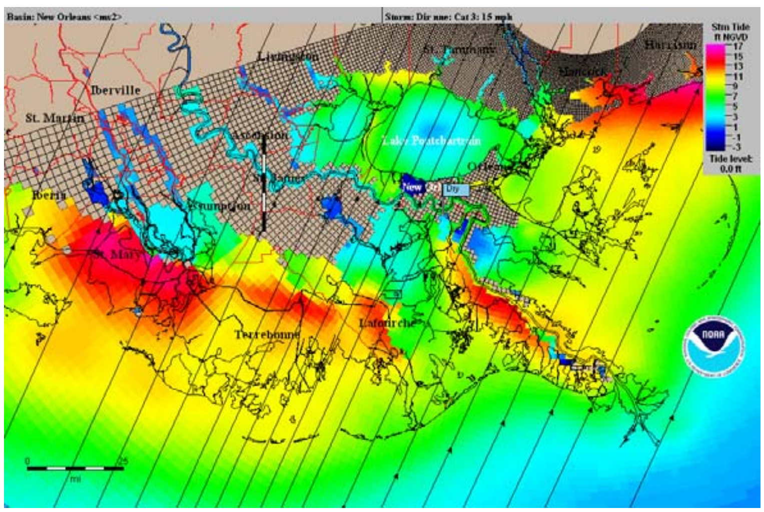
Forward Speed: 15 mph



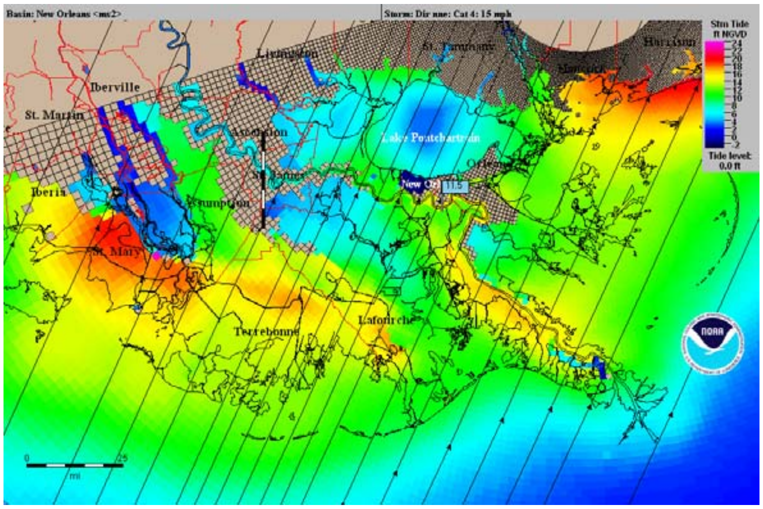
Category 1



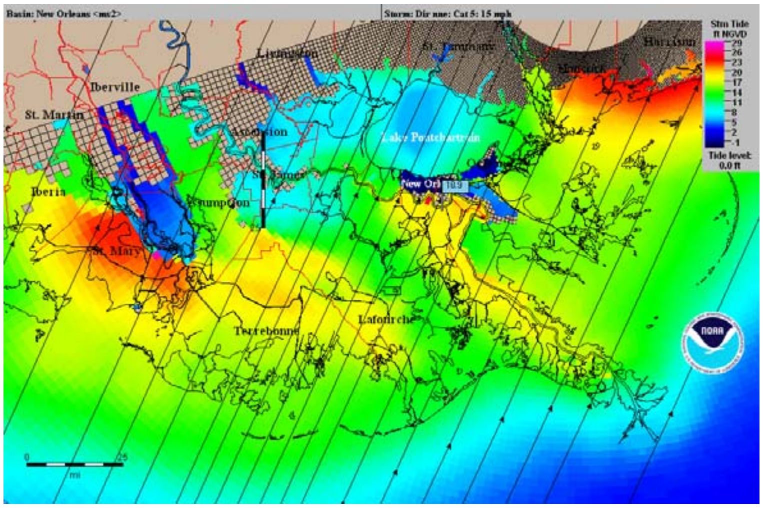
Category 2



Category 3



Category 4

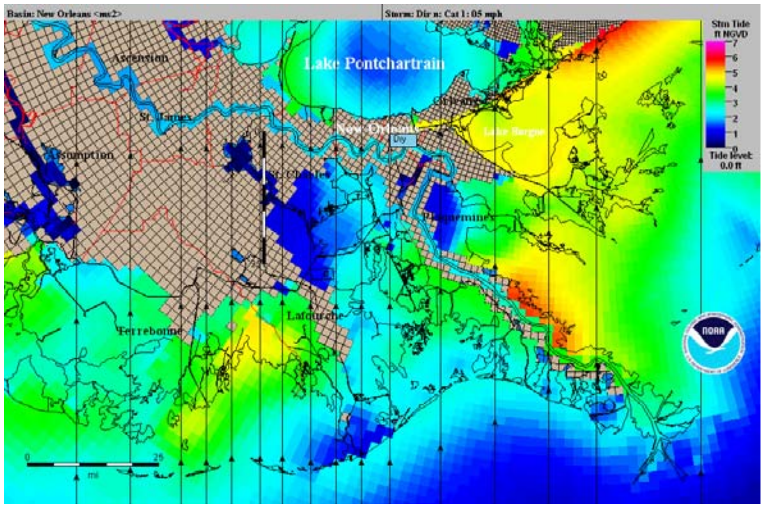


Category 5

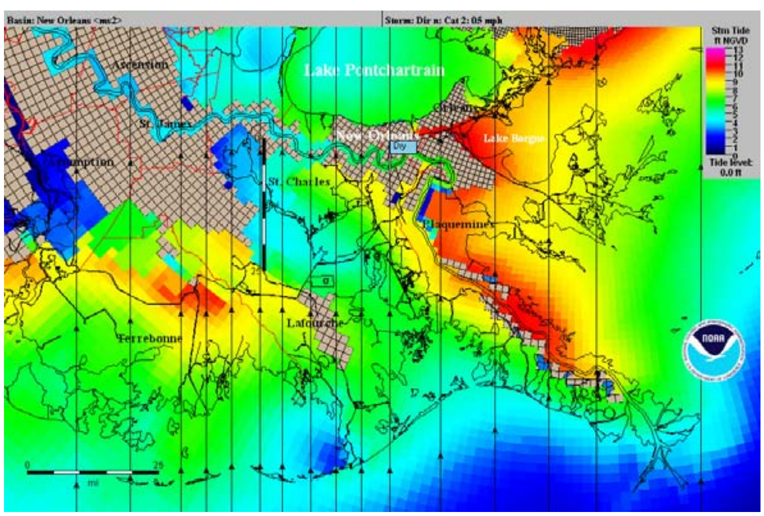
Direction: NORTH

Forward Speed: 5 mph

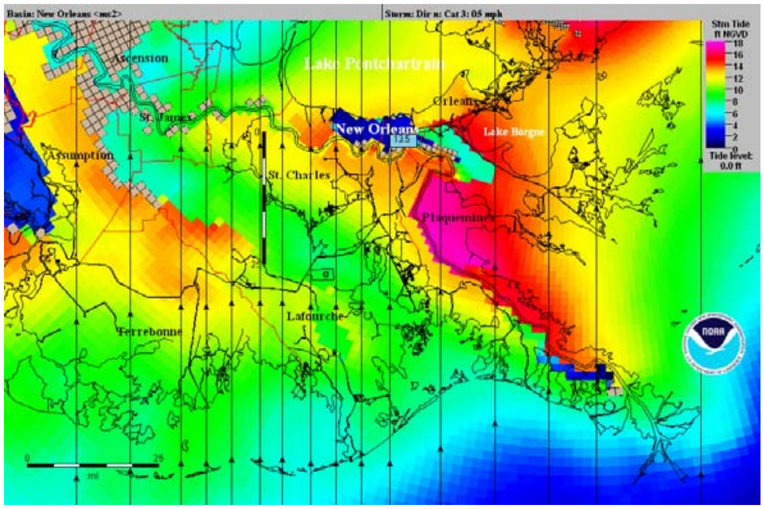
Low Tide



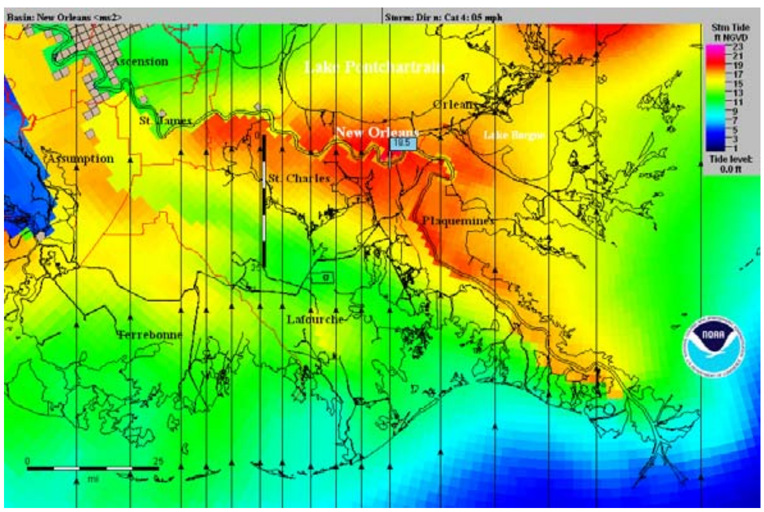
Category 1



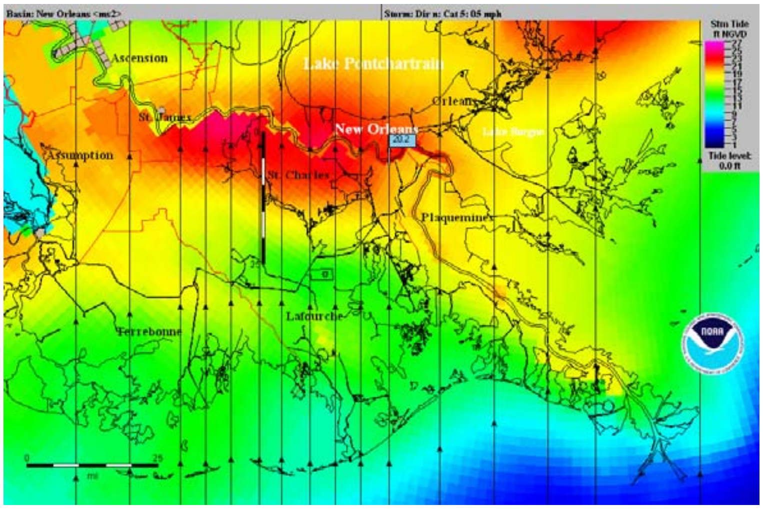
Category 2



Category 3

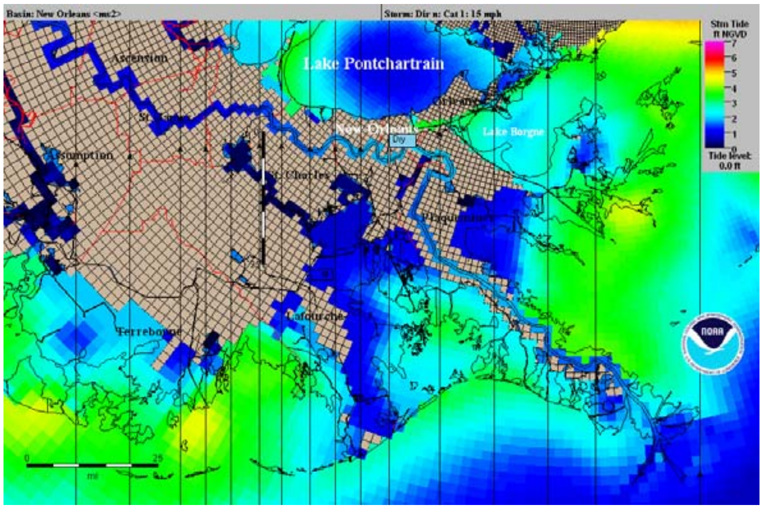


Category 4

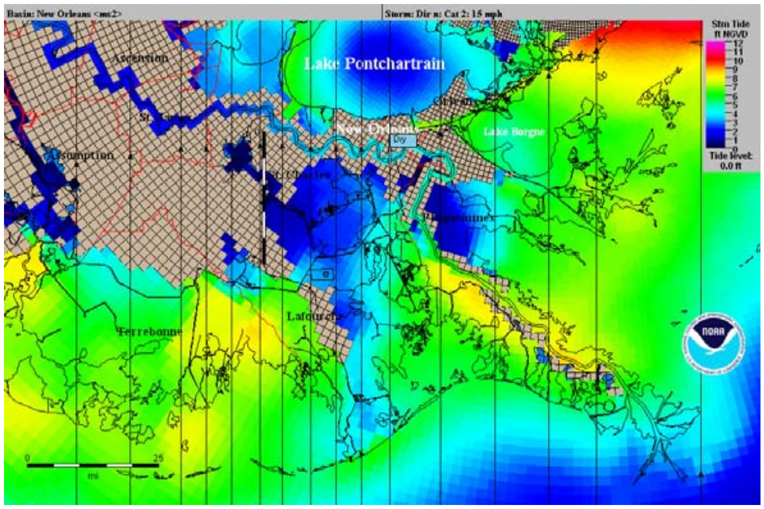


Category 5

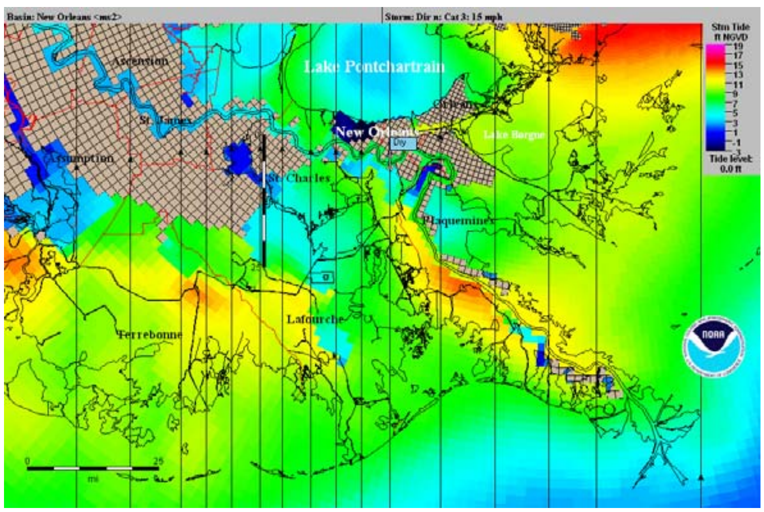
Forward Speed: 15 mph



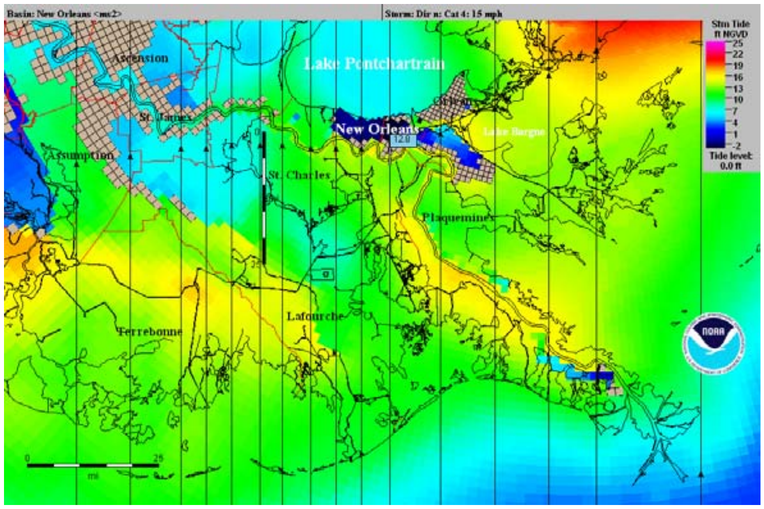
Category 1



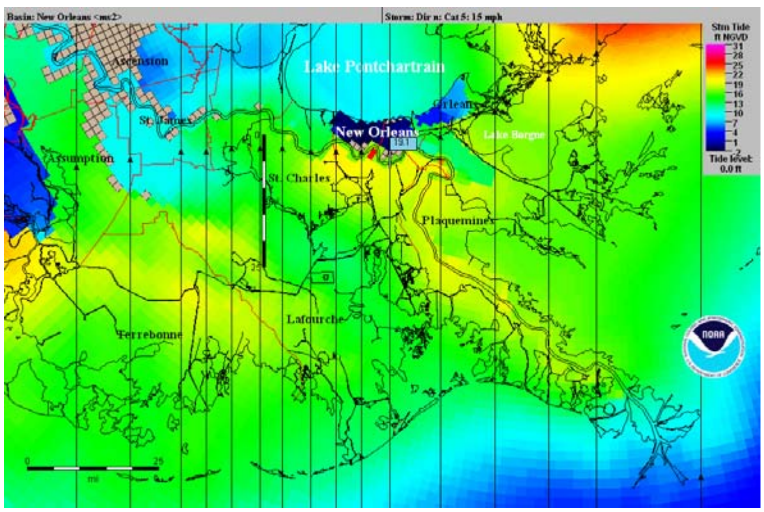
Category 2



Category 3



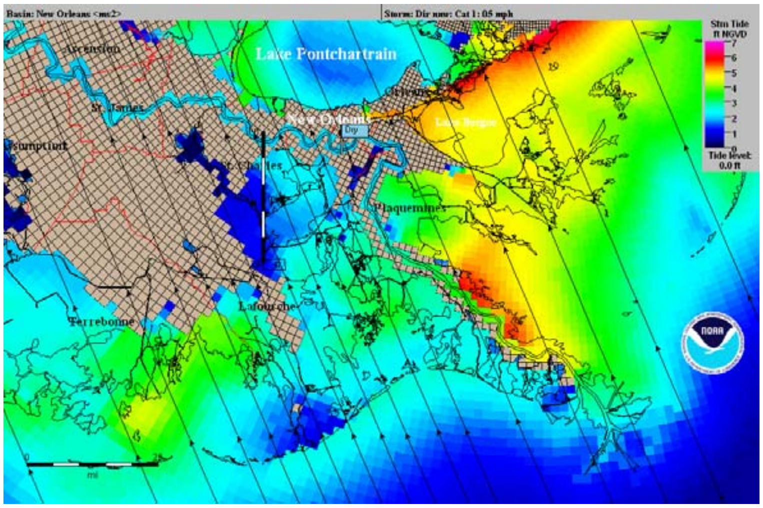
Category 4



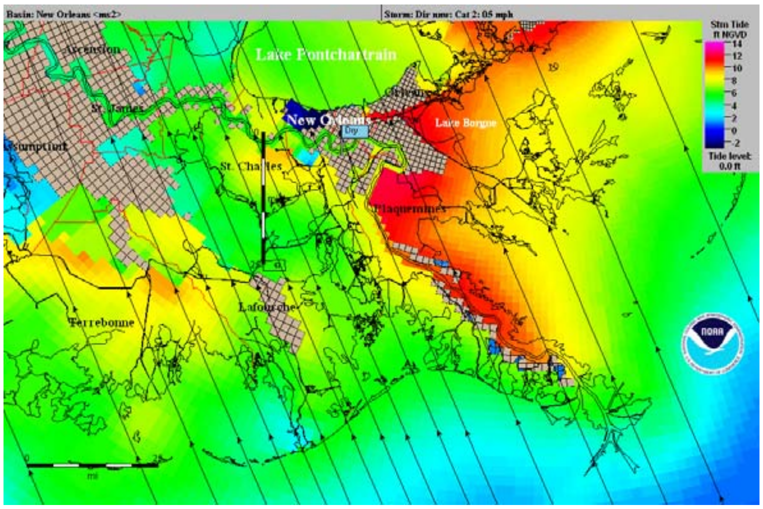
Category 5

Direction: North Northwest

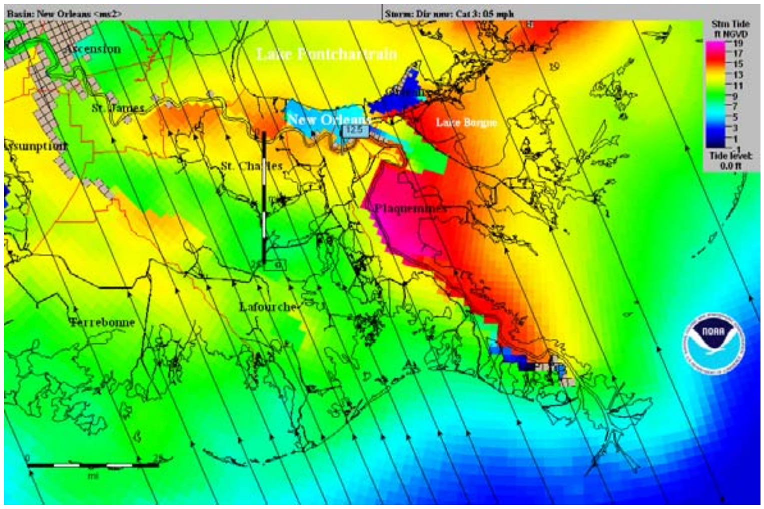
Forward Speed: 5 mph



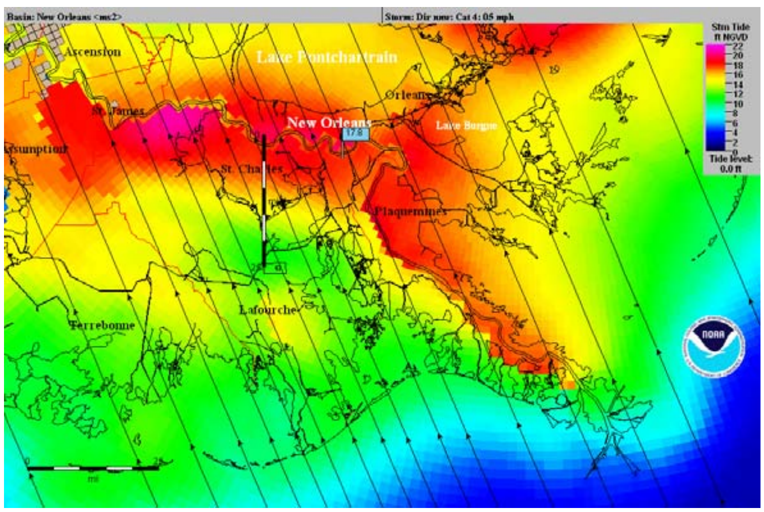
Category 1



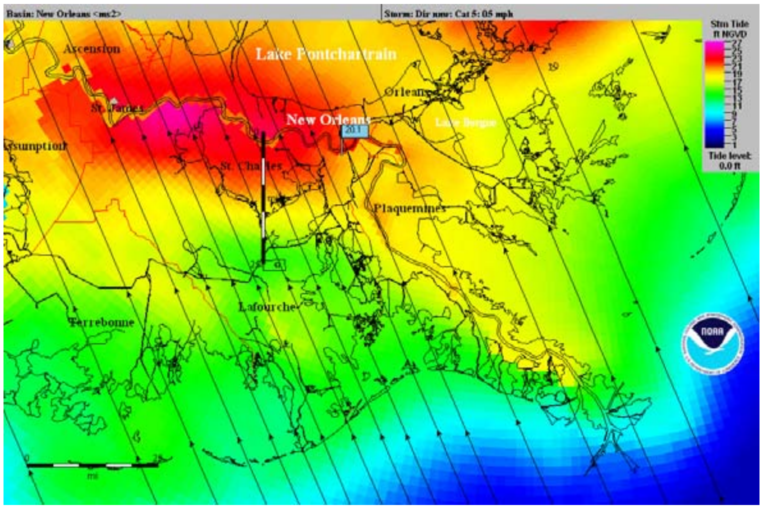
Category 2



Category 3

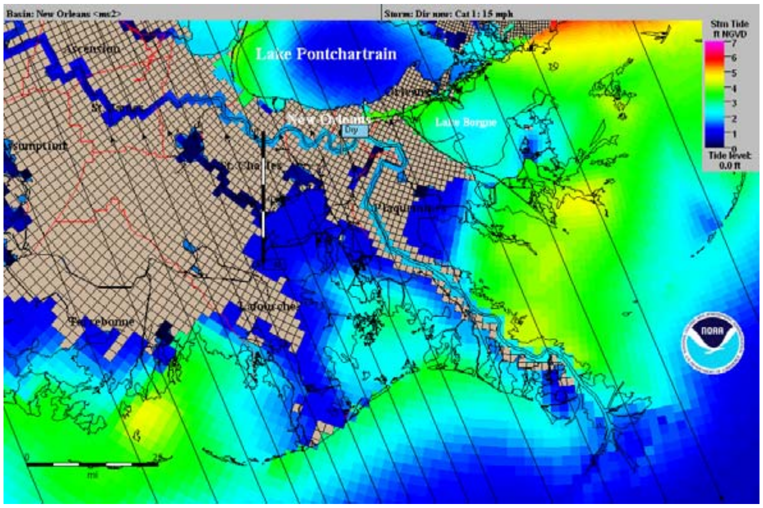


Category 4

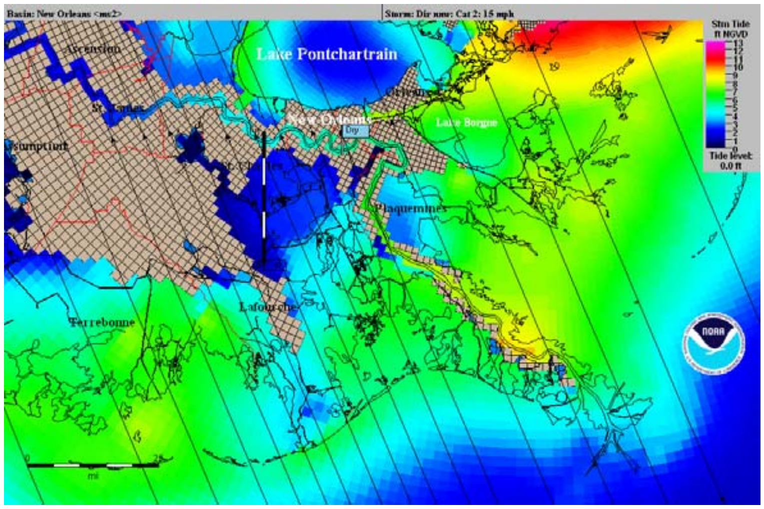


Category 5

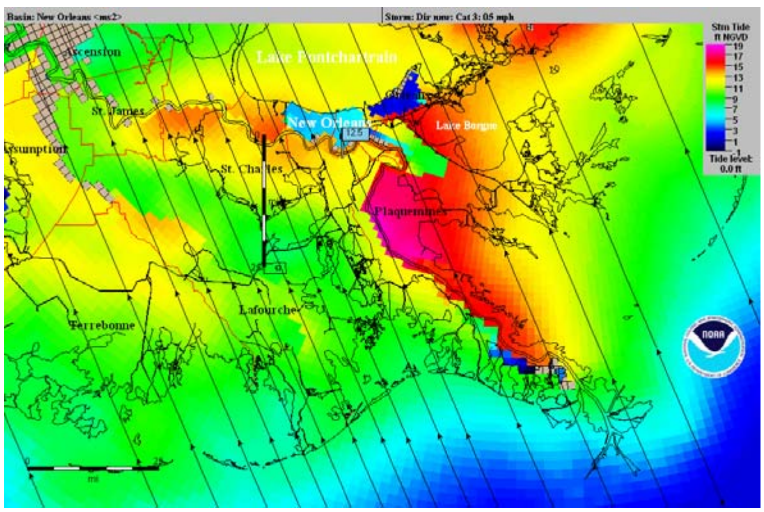
Forward Speed: 15 mph



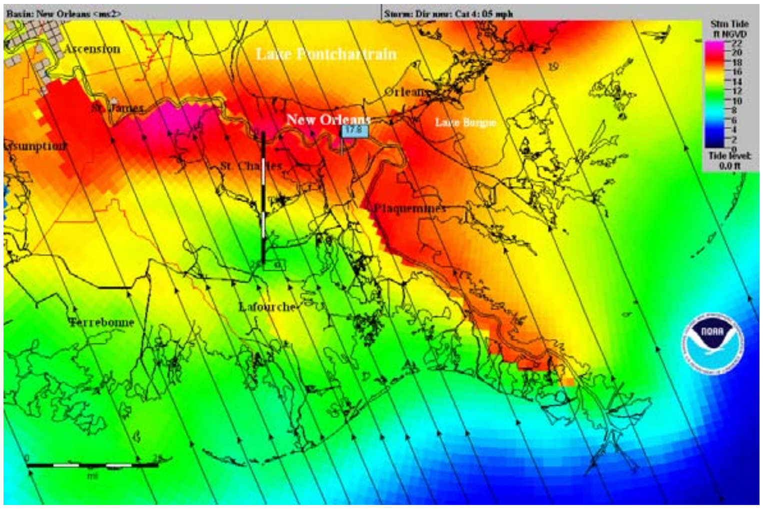
Category 1



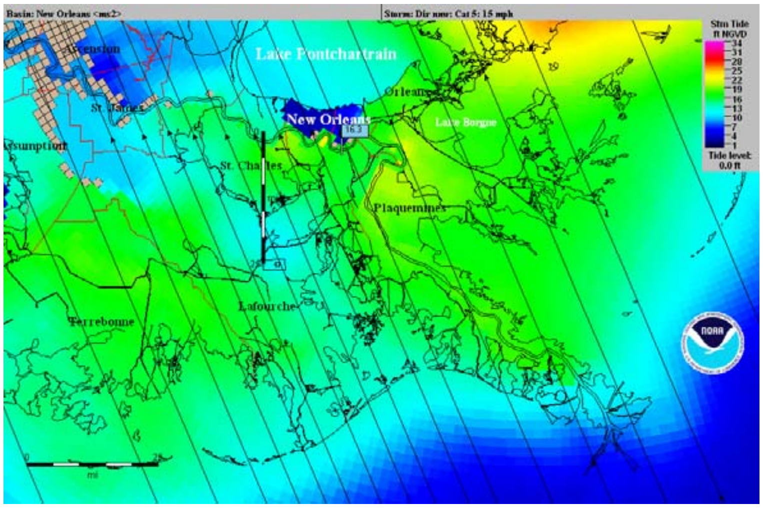
Category 2



Category 3



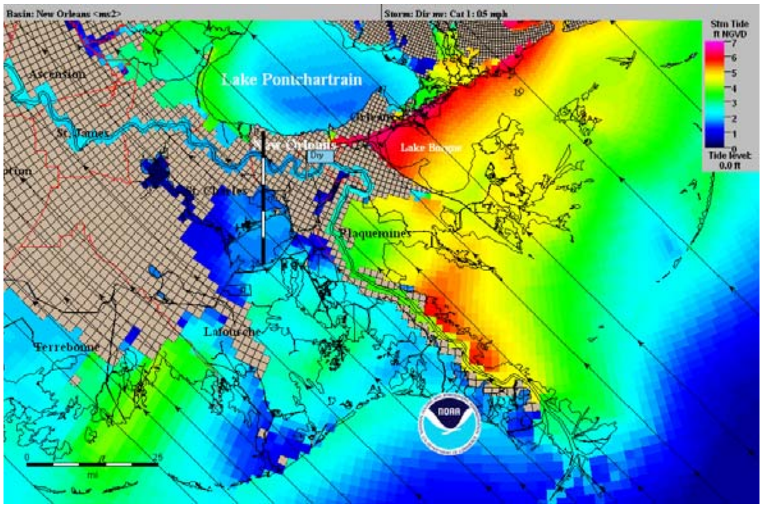
Category 4



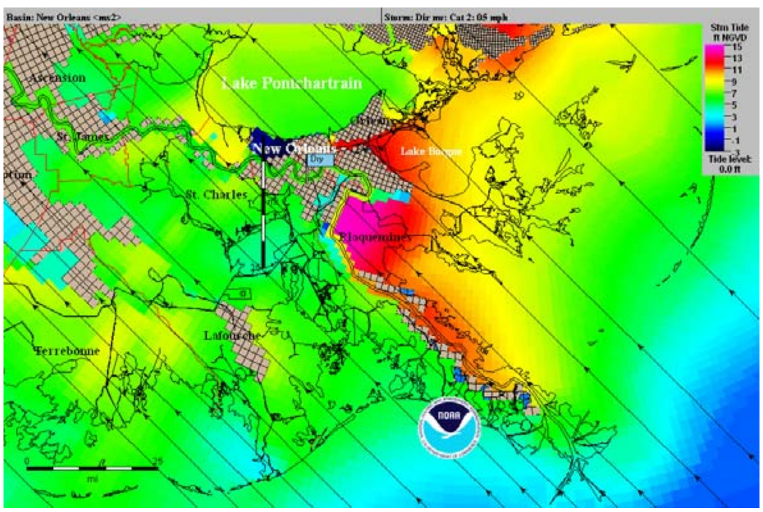
Category 5

Direction: Northwest

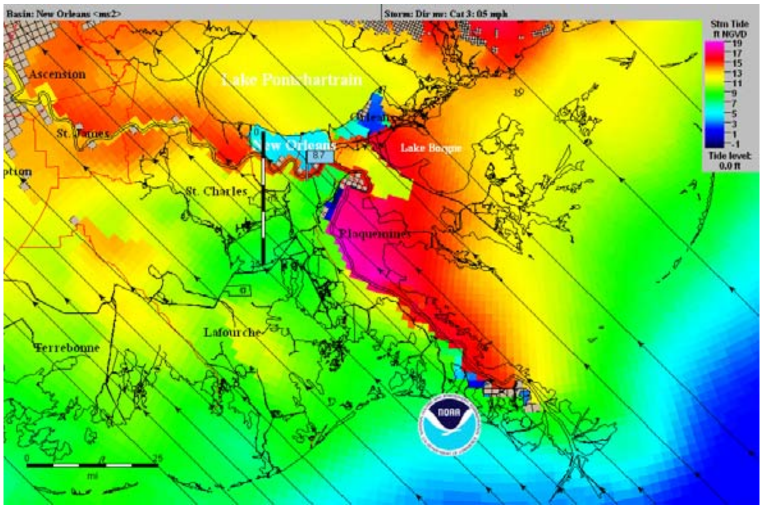
Forward Speed: 5 mph



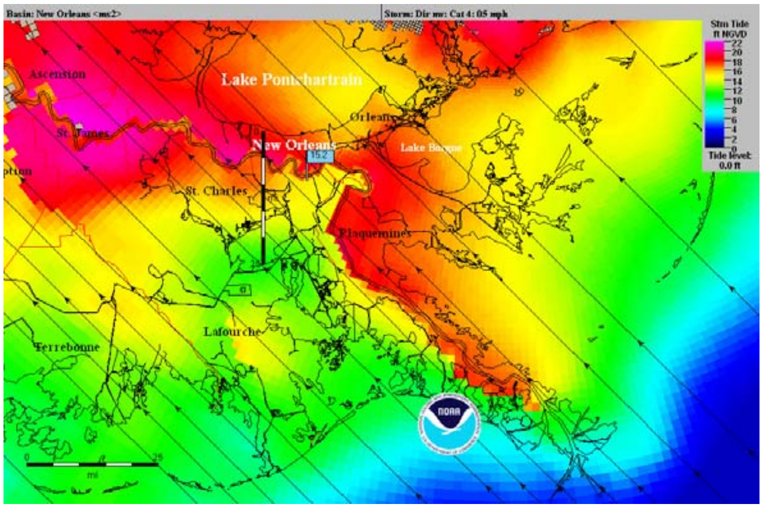
Category 1



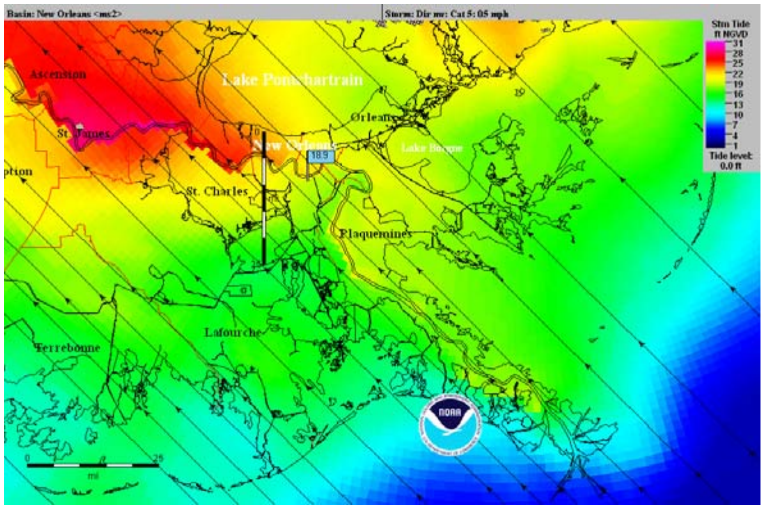
Category 2



Category 3

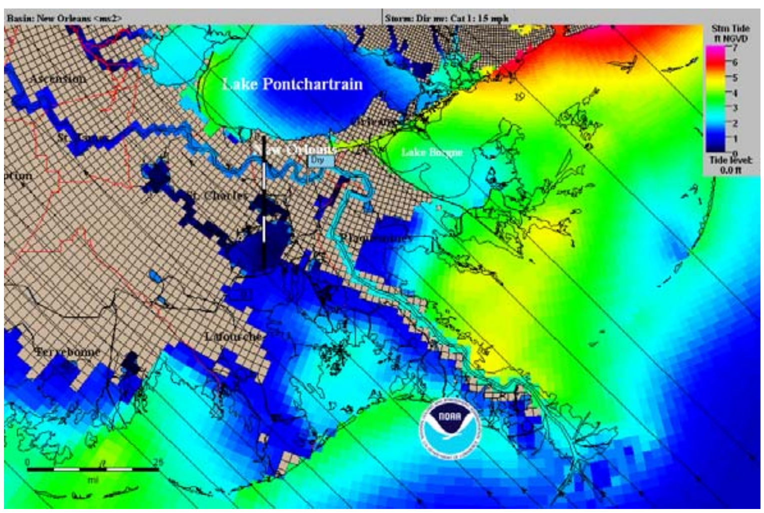


Category 4

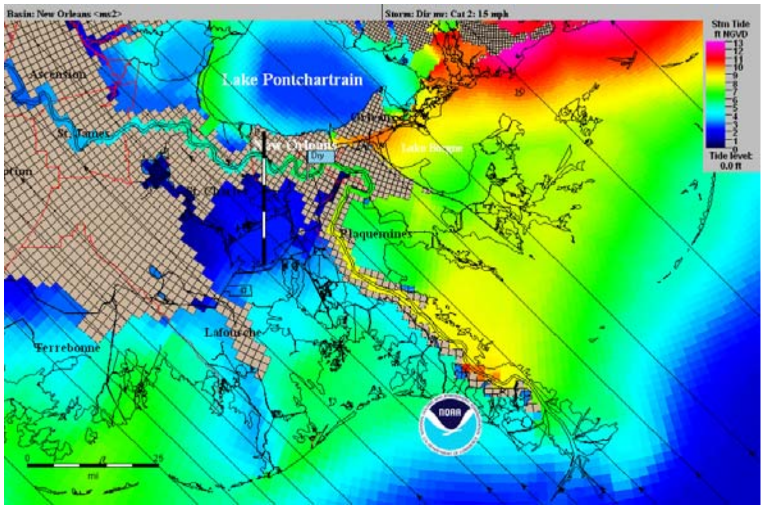


Category 5

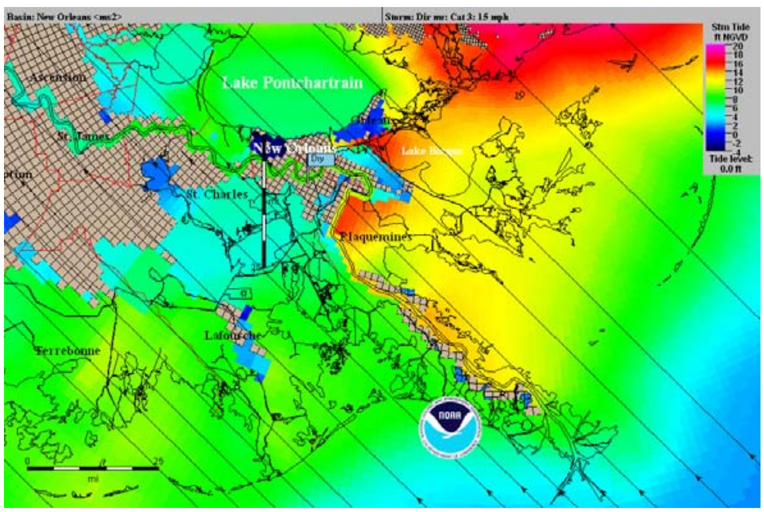
Forward Speed: 15 mph



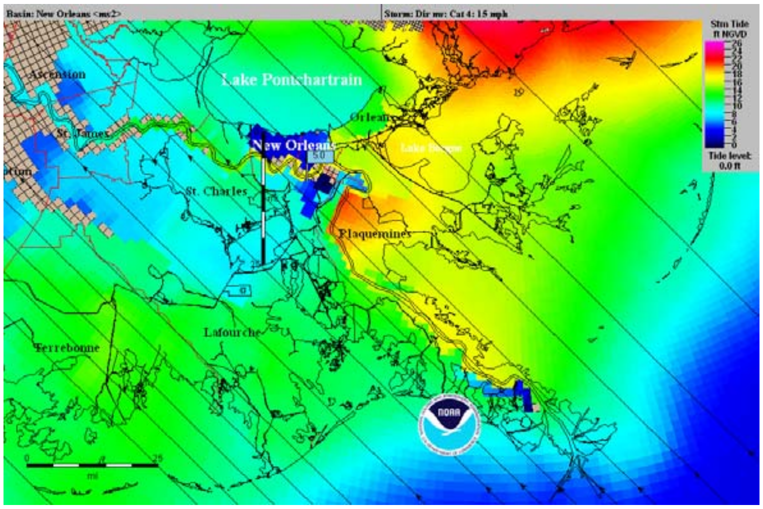
Category 1



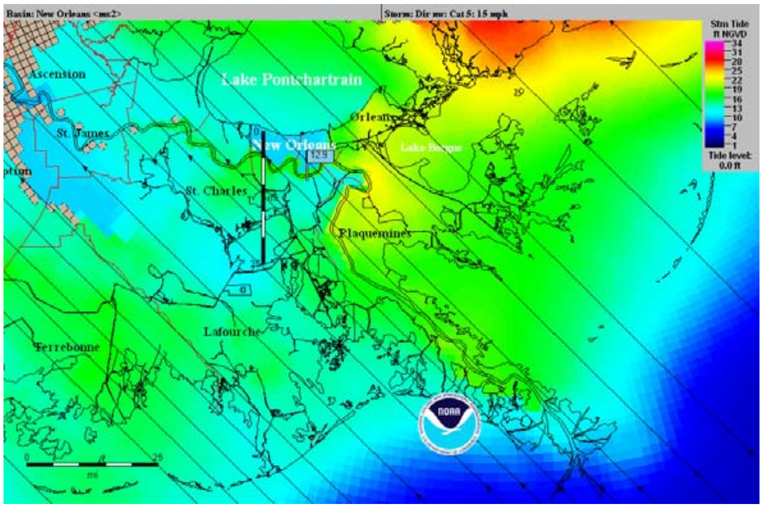
Category 2



Category 3



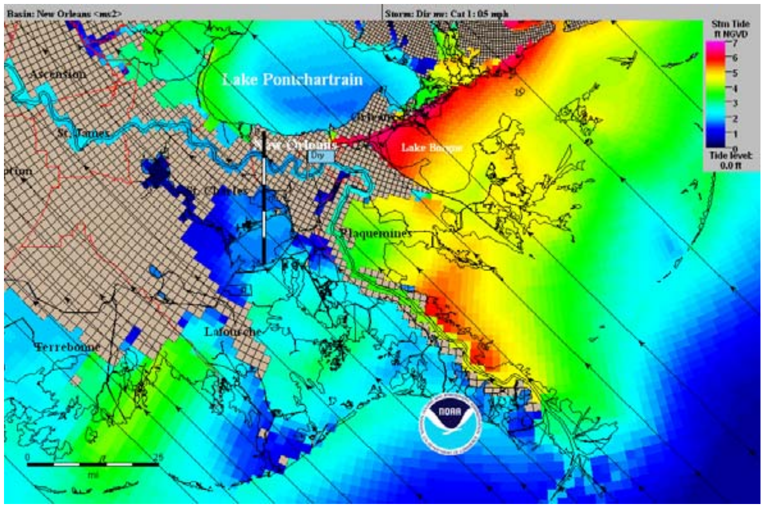
Category 4



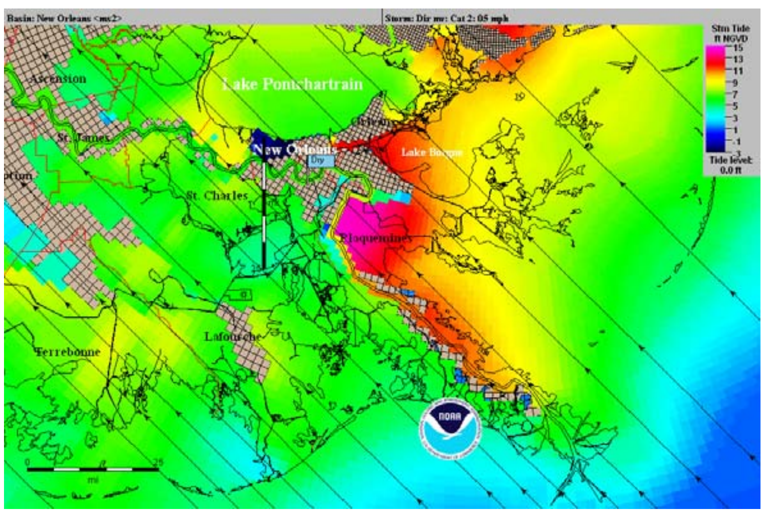
Category 5

Direction: West Northwest

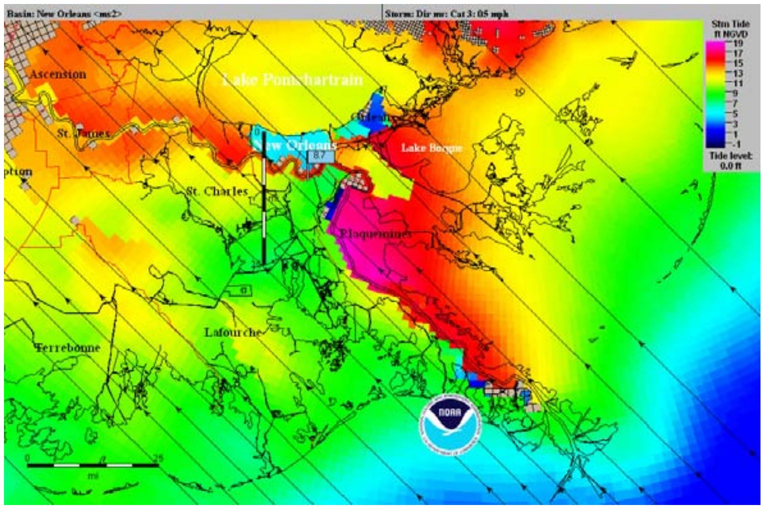
Forward Speed: 5 mph



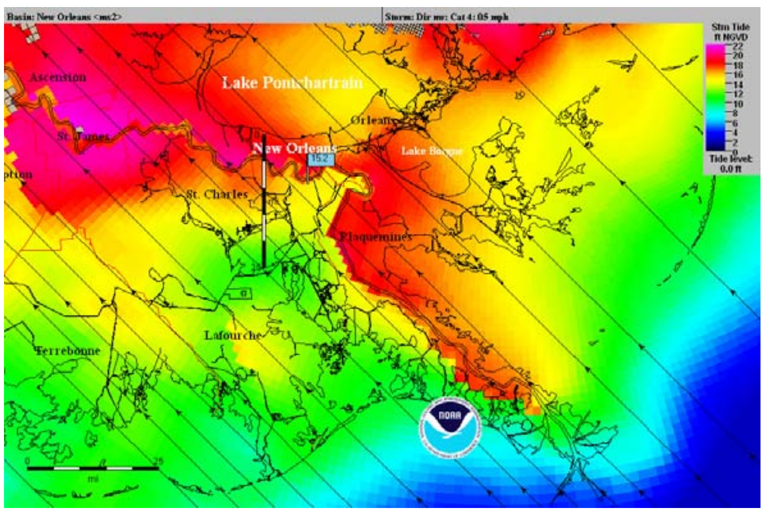
Category 1



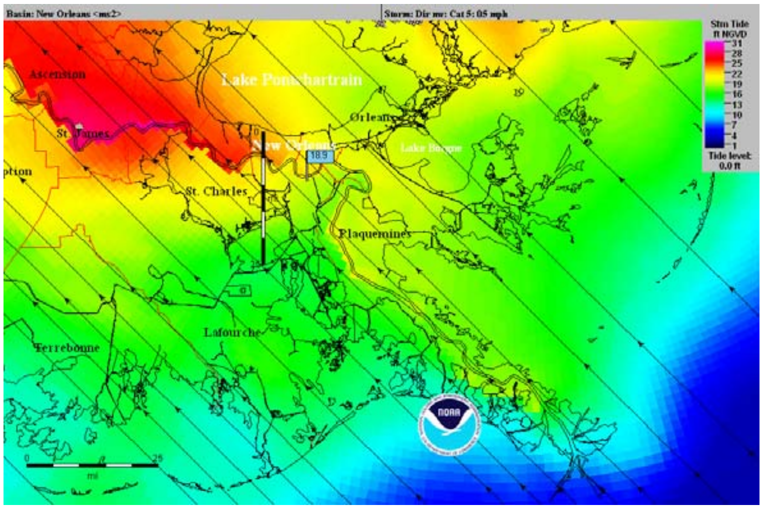
Category 2



Category 3

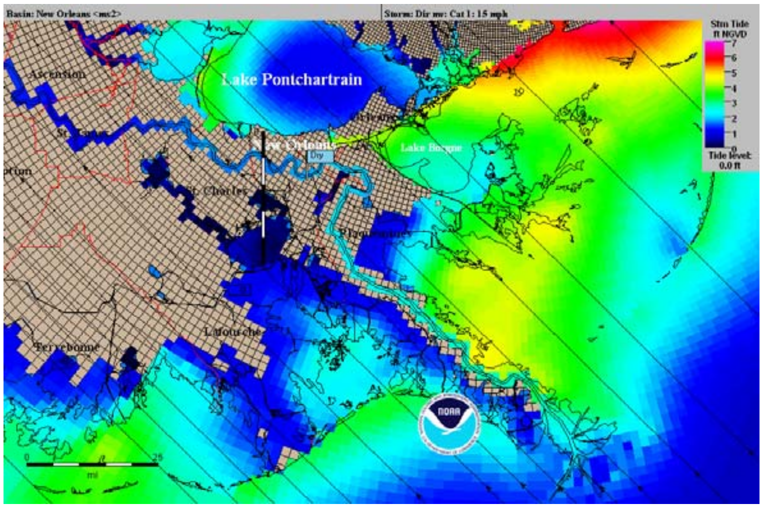


Category 4

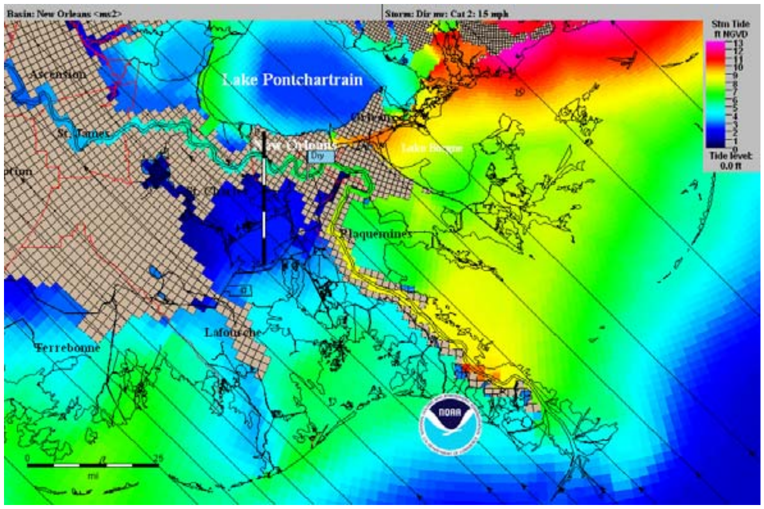


Category 5

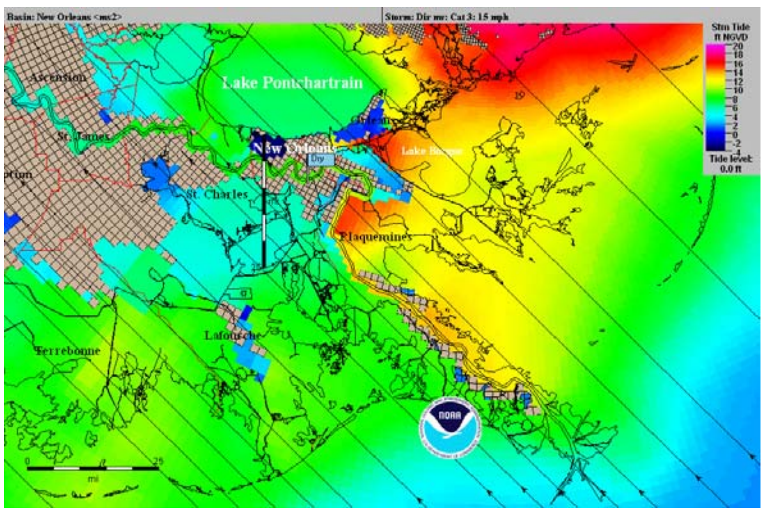
Forward Speed: 15 mph



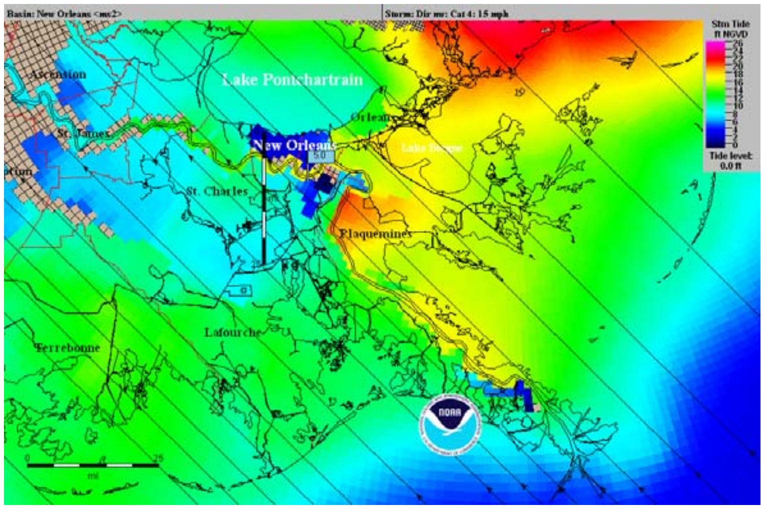
Category 1



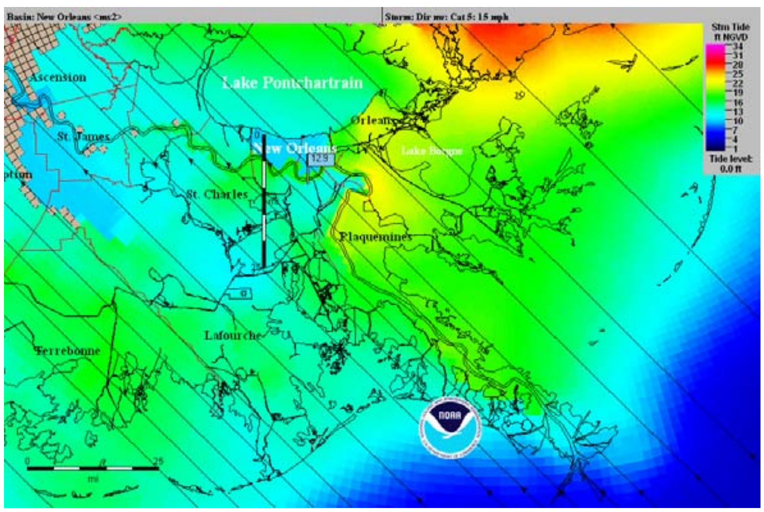
Category 2



Category 3



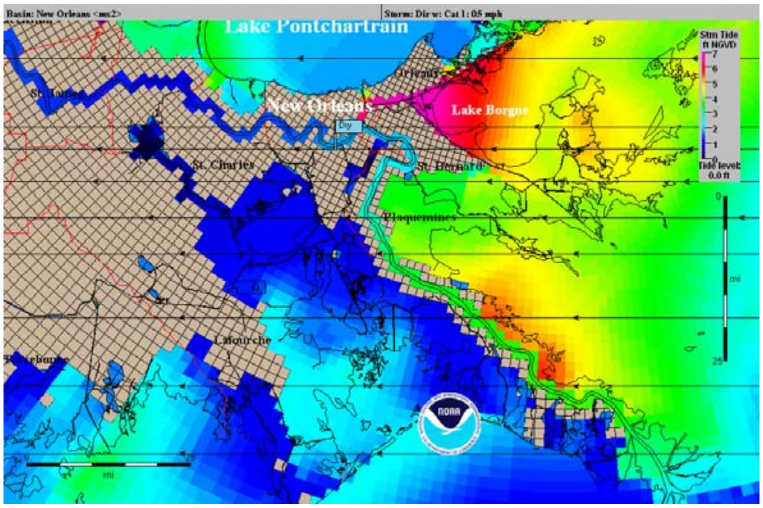
Category 4



Category 5

Direction: West

Forward Speed: 5 mph



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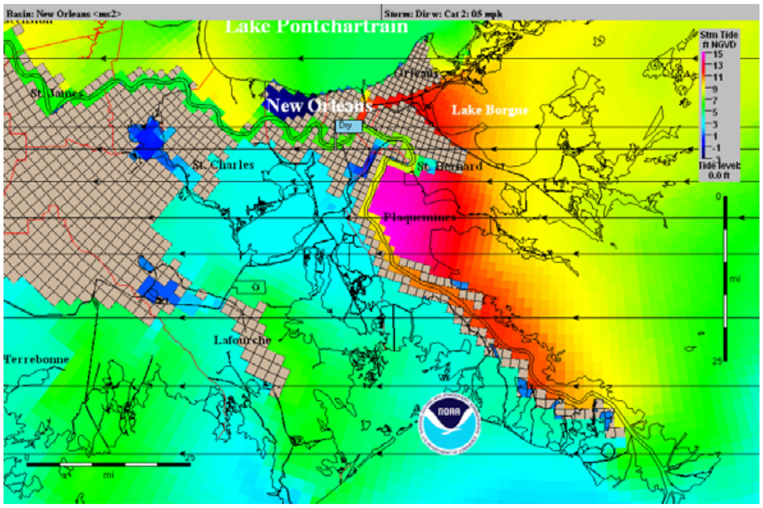

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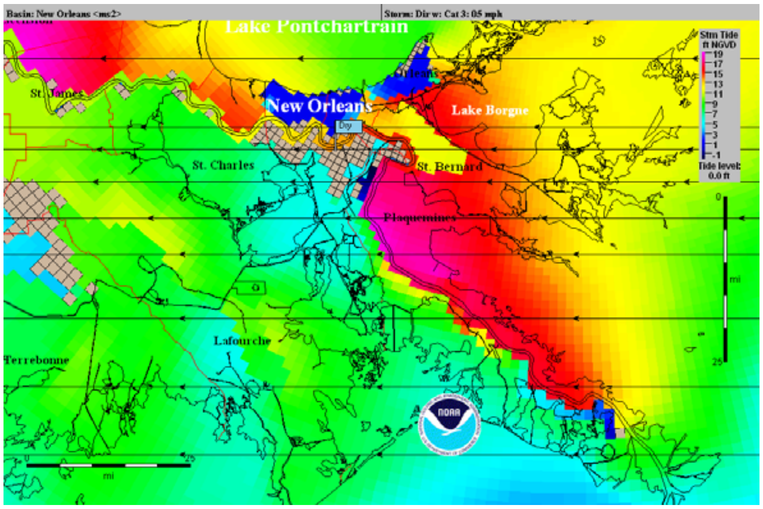

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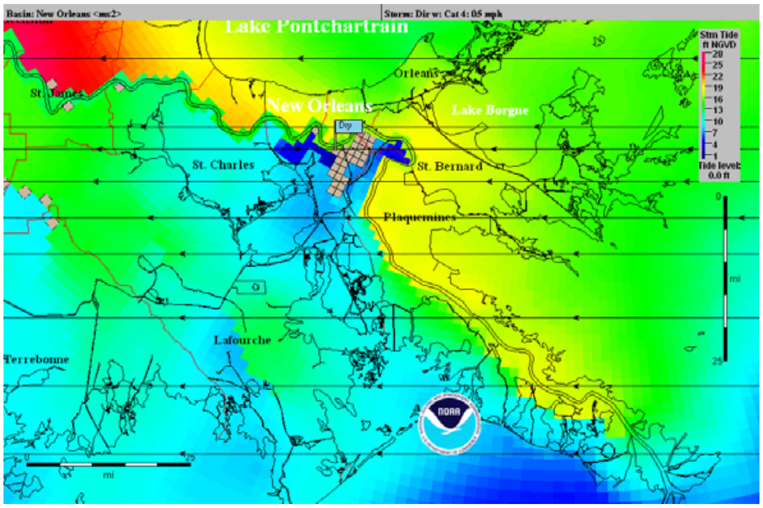

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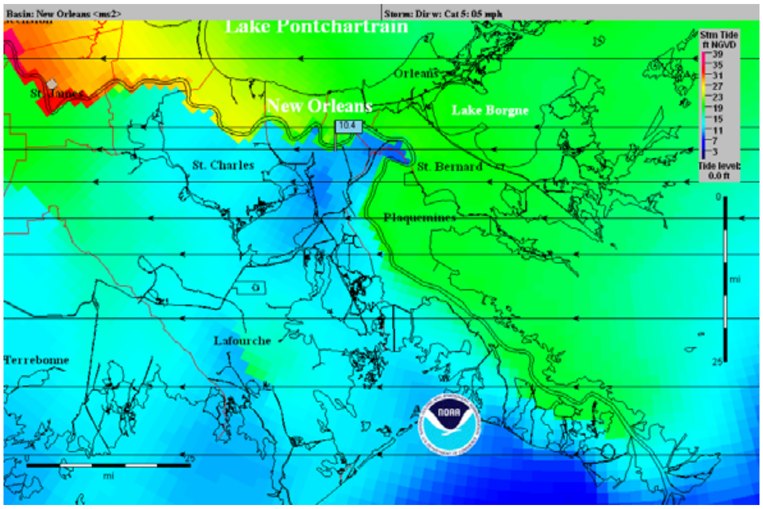
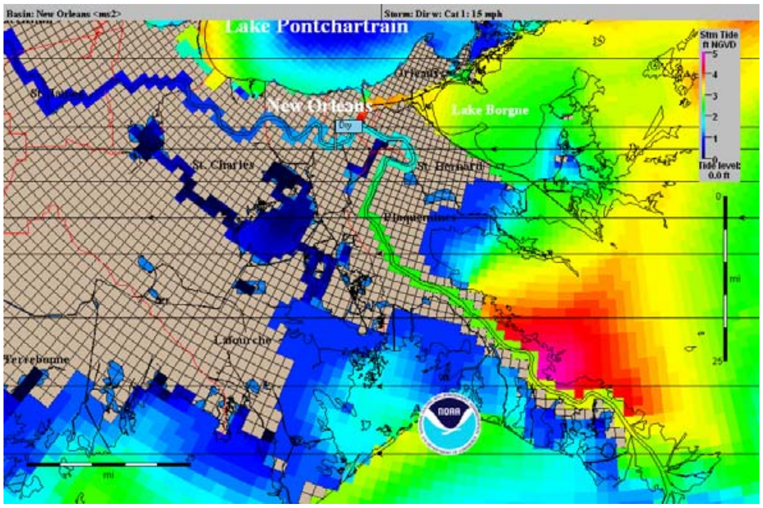
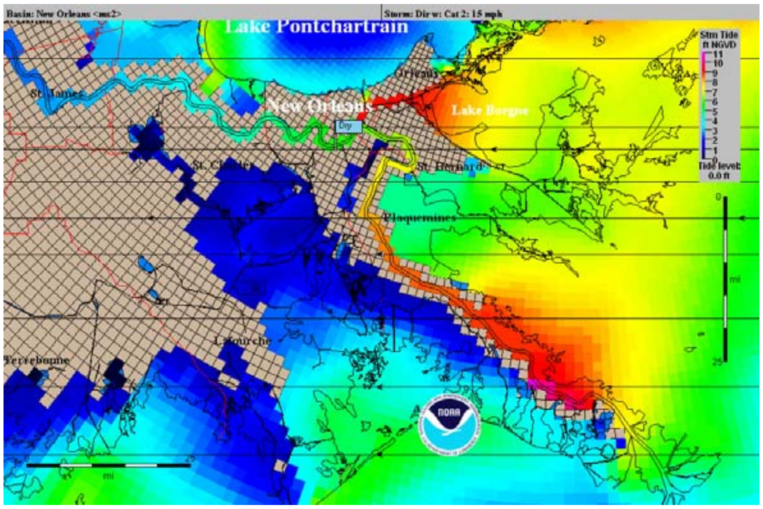


Category 5

Forward Speed: 15 mph



Category 1



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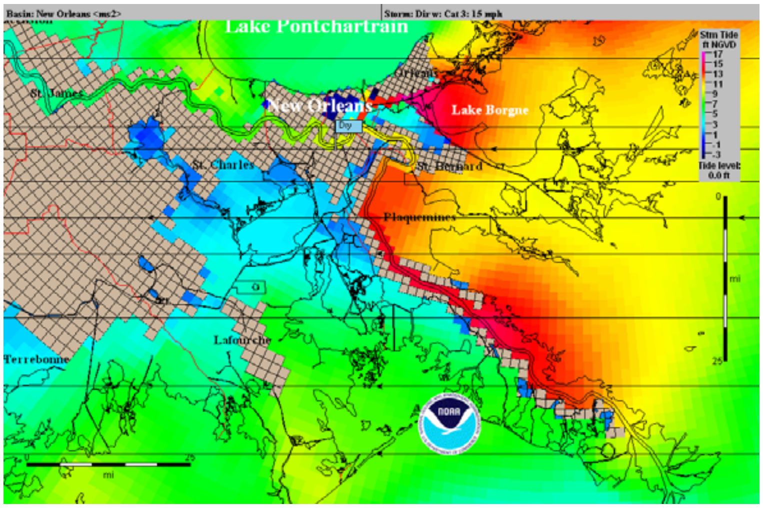

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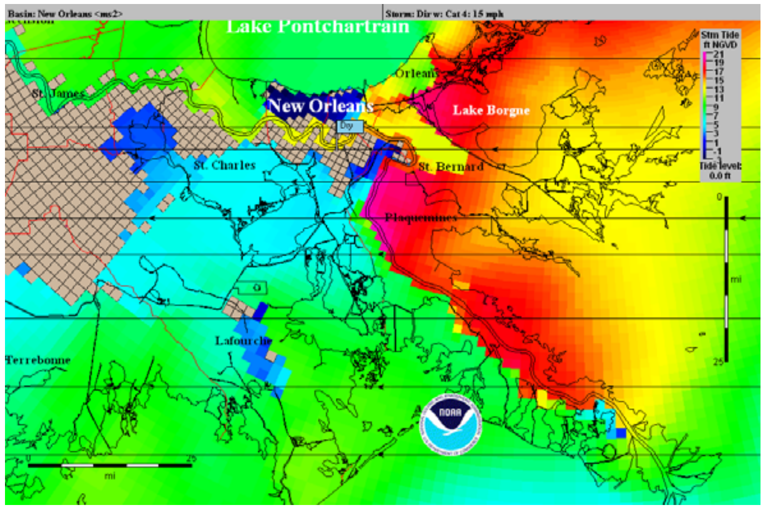

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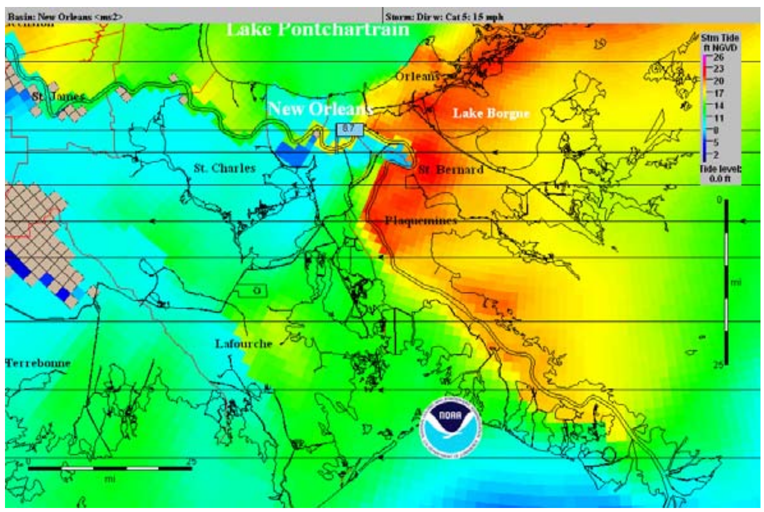


Category 5

APPENDIX E

WEST JEFFERSON MEDICAL CENTER WIND TUNNEL MODEL PRESSURE RESULTS

South Wing port and tap arrangement

	Port 1	Port 2	Port 3	Port 4	Port 5	Port 6	Port 7	Port 8	Port 9	Port 10	Port 11	Port 12
Chan #1	Reserved for Pitot tube											
Chan #2												
Chan #3												
Chan #4	8A01	0A03	00K01	8A14	8C10	6C01	6A01	1A01	3B01	5B02	0C01	0RL1
Chan #5	8A02	0C02	00L01	8A15	8C11	6C02	6A02	1A02	3B02	5C01	0B02	0RL2
Chan #6	8A03	0A02	00L02	8B01	8C12	6C03	6A03	1A03	3C01	5C02	0B01	0RL3
Chan #7	8A04	0C03	9J01	8B02	8C13	6C04	6A04	1A04	3C02	5C03	0A04	0RL4
Chan #8	8A05	0RM1	9L01	8C01	8C14	6C05	6A05	2A01	4A01	5C04	0RR1	0RL5
Chan #9	8A06	0RM2	9L02	8C02	8D01	7C01	7A01	2C01	4C01	5D01	0RR2	0RL6
Chan #10	8A07	0RM3	10J01	8C03	8D02	7C02	7A02	2C02	4C02	5F01	0RR3	0RL7
Chan #11	8A08	0RM4	10K01	8C04	8F01	7C03	7A03	2C03	4C04	5F02	0RR4	0RL8
Chan #12	8A09	0RM5	10K02	8C05	8F02	7C04	7A04	2C04	4C05	6D01	0RR5	0RL13
Chan #13	8A10	0RM6	10L01	8C06	7E01	7C06	7A05	2C05	5A01	6D02	0RR6	0RL12
Chan #14	8A11	0RM7	10L02	8C07	7E02	7C07	7A06	3A01	5A02	6F01	0RR7	0RL11
Chan #15	8A12	0RM8	10J02	8C08	7F01	7C08	7C05	3A02	5A03	6F02	0RR8	0RL10
Chan #16	8A13	0RM9	0A01	8C09	7F02	7D01	00J01	3A03	5B01	7B01	0D01	0RL9

	Port 1 Mean Pressure Coefficients												
	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Angle	**8A01**	**8A02**	**8A03**	**8A04**	**8A05**	**8A06**	**8A07**	**8A08**	**8A09**	**8A10**	**8A11**	**8A12**	**8A13**
0	-0.09	0.52	0.42	0.58	0.54	0.67	0.60	0.66	0.60	0.71	0.69	0.73	0.91
15	-0.46	0.38	0.27	0.40	0.34	0.55	0.40	0.54	0.41	0.63	0.50	0.68	0.82
30	-0.55	0.22	0.12	0.19	0.12	0.34	0.14	0.34	0.16	0.43	0.24	0.55	0.60
45	-0.42	0.18	0.09	0.09	0.02	0.22	0.01	0.20	-0.02	0.33	0.09	0.30	0.23
60	-0.25	0.25	0.18	0.12	0.06	0.21	0.04	0.15	-0.05	0.31	0.08	0.06	-0.01
75	-0.17	0.32	0.28	0.17	0.15	0.23	0.12	0.15	0.03	0.28	0.16	-0.15	-0.14
90	0.07	0.52	0.49	0.40	0.38	0.40	0.33	0.35	0.27	0.39	0.28	0.10	0.15
105	-0.06	0.26	0.25	0.20	0.20	0.18	0.19	0.12	0.13	0.08	0.08	-0.02	0.10
120	-0.29	-0.13	-0.14	-0.13	-0.13	-0.11	-0.12	-0.19	-0.18	-0.24	-0.24	-0.34	-0.22
135	-0.53	-0.55	-0.56	-0.53	-0.52	-0.48	-0.49	-0.67	-0.60	-0.73	-0.70	-0.79	-0.65
150	-0.69	-0.76	-0.76	-0.75	-0.74	-0.73	-0.73	-0.86	-0.82	-0.92	-0.88	-0.90	-0.78
165	-0.84	-0.84	-0.85	-0.82	-0.81	-0.88	-0.87	-0.98	-0.95	-1.03	-1.00	-1.03	-0.90
180	-0.99	-0.93	-0.94	-0.87	-0.84	-0.85	-0.85	-0.92	-0.90	-0.96	-0.94	-1.01	-0.86
195	-1.04	-0.94	-0.96	-0.91	-0.89	-0.88	-0.88	-0.96	-0.95	-1.01	-1.00	-1.06	-0.92
210	-0.96	-0.93	-0.94	-0.91	-0.90	-0.94	-0.90	-1.00	-0.96	-1.05	-1.01	-1.08	-0.91
225	-0.78	-0.83	-0.85	-0.83	-0.82	-0.83	-0.83	-0.87	-0.86	-0.91	-0.90	-0.95	-0.81
240	-0.74	-0.91	-0.93	-0.90	-0.91	-0.88	-0.89	-0.85	-0.86	-0.86	-0.87	-0.91	-0.78
255	-0.61	-0.87	-0.86	-0.85	-0.83	-0.76	-0.78	-0.75	-0.75	-0.79	-0.79	-0.85	-0.71
270	-0.43	-0.70	-0.70	-0.70	-0.68	-0.62	-0.65	-0.57	-0.60	-0.56	-0.59	-0.58	-0.47
285	-0.35	-0.70	-0.70	-0.69	-0.67	-0.58	-0.61	-0.50	-0.52	-0.41	-0.45	-0.34	-0.25
300	-0.27	-0.55	-0.55	-0.42	-0.39	-0.18	-0.17	-0.04	-0.01	0.01	0.07	-0.01	0.24
315	-0.23	-0.08	-0.12	0.38	0.46	0.54	0.65	0.39	0.58	0.31	0.52	0.26	0.61
330	-0.06	0.29	0.27	0.49	0.53	0.51	0.55	0.53	0.58	0.51	0.62	0.49	0.73
345	0.16	0.43	0.35	0.52	0.51	0.67	0.62	0.73	0.71	0.74	0.74	0.72	0.89

	Port 2 Mean Pressure Coefficients												
	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Angle	**0A03**	**0C02**	**0A02**	**0C03**	**0RM1**	**0RM2**	**0RM3**	**0RM4**	**0RM5**	**0RM6**	**0RM7**	**0RM8**	**0RM9**
0	-1.90	-1.07	-1.61	-1.12	-1.55	-1.51	-1.41	-1.44	-1.33	-1.33	-1.13	-1.15	-1.40
15	-2.25	-0.90	-1.71	-1.18	-1.76	-1.76	-1.60	-1.65	-1.47	-1.46	-1.21	-1.20	-1.57
30	-2.31	-0.67	-1.70	-1.14	-1.81	-1.86	-1.65	-1.71	-1.48	-1.44	-1.19	-1.14	-1.60
45	-2.22	-0.48	-1.61	-0.91	-1.70	-1.77	-1.50	-1.56	-1.25	-1.18	-0.94	-0.93	-1.40
60	-1.90	-0.45	-1.37	-0.66	-1.40	-1.47	-1.23	-1.23	-0.94	-0.83	-0.71	-0.70	-1.08
75	-1.06	-0.28	-0.72	-0.23	-0.71	-0.73	-0.49	-0.48	-0.33	-0.30	-0.32	-0.36	-0.39
90	-0.07	0.04	0.04	0.03	0.03	0.03	0.10	0.08	0.06	0.06	-0.01	0.00	0.07
105	0.20	-0.05	0.32	0.04	0.20	0.17	0.17	0.13	0.09	0.08	0.02	0.00	0.11
120	0.00	-0.28	0.11	-0.29	-0.02	-0.04	-0.06	-0.08	-0.12	-0.12	-0.18	-0.19	-0.11
135	-0.16	-1.16	-0.14	-1.00	-0.30	-0.31	-0.37	-0.37	-0.49	-0.48	-0.67	-0.73	-0.42
150	-0.35	-1.46	-0.39	-1.29	-0.56	-0.55	-0.65	-0.62	-0.76	-0.75	-0.97	-1.06	-0.69
165	-0.73	-2.09	-0.64	-2.11	-0.91	-0.88	-1.06	-1.05	-1.27	-1.28	-1.68	-1.77	-1.14
180	-0.96	-2.04	-0.62	-2.32	-1.06	-1.04	-1.28	-1.27	-1.51	-1.47	-1.81	-1.83	-1.36
195	-0.96	-2.16	-0.50	-2.68	-1.00	-1.02	-1.32	-1.33	-1.71	-1.60	-1.96	-1.97	-1.50
210	-0.72	-2.32	-0.65	-2.61	-0.84	-0.82	-1.06	-1.11	-1.52	-1.50	-1.83	-1.93	-1.29
225	-0.50	-2.03	-0.71	-2.06	-0.73	-0.65	-0.78	-0.78	-1.06	-1.06	-1.36	-1.44	-0.89
240	-0.61	-1.60	-0.75	-1.49	-0.74	-0.69	-0.72	-0.69	-0.82	-0.81	-1.03	-1.10	-0.73
255	-0.63	-0.91	-0.80	-0.85	-0.70	-0.63	-0.63	-0.60	-0.63	-0.57	-0.65	-0.71	-0.60
270	-0.64	-0.48	-0.75	-0.55	-0.73	-0.66	-0.57	-0.55	-0.52	-0.47	-0.46	-0.51	-0.53
285	-0.58	-0.34	-0.71	-0.49	-0.70	-0.63	-0.61	-0.57	-0.52	-0.45	-0.41	-0.42	-0.54
300	-0.79	-0.38	-0.73	-0.54	-0.70	-0.63	-0.59	-0.55	-0.53	-0.47	-0.46	-0.46	-0.54
315	-1.55	-0.21	-1.43	-0.38	-1.11	-0.96	-0.65	-0.65	-0.48	-0.44	-0.36	-0.42	-0.55
330	-1.72	-0.48	-1.70	-0.41	-1.42	-1.33	-0.96	-0.99	-0.73	-0.71	-0.53	-0.62	-0.85
345	-1.79	-0.88	-1.72	-0.84	-1.56	-1.49	-1.29	-1.31	-1.14	-1.11	-0.91	-0.95	-1.23

	Port 3 Mean Pressure Coefficients												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**00K01**	**00L01**	**00L02**	**9J01**	**9L01**	**9L02**	**10J01**	**10K01**	**10K02**	**10L01**	**10L02**	**10J02**	**0A01**
0	-0.968	-0.818	-1.094	-1.482	-1.033	-1.140	-1.185	-0.917	-0.981	-1.077	-1.248	-1.234	-1.467
15	-1.382	-1.263	-1.355	-1.492	-1.155	-1.227	-1.210	-1.037	-1.106	-1.205	-1.366	-1.340	-1.471
30	-1.465	-1.407	-1.491	-1.521	-1.261	-1.268	-1.220	-1.054	-1.134	-1.301	-1.292	-1.381	-1.471
45	-1.310	-1.276	-1.309	-1.313	-1.126	-1.109	-0.999	-0.917	-1.007	-1.118	-1.146	-1.138	-1.337
60	-1.176	-1.119	-1.183	-1.068	-1.117	-1.038	-0.810	-0.876	-0.989	-1.104	-1.063	-0.959	-1.130
75	-1.111	-1.032	-1.206	-0.265	-1.053	-0.978	-0.067	-0.721	-1.046	-1.063	-1.016	-0.303	-0.431
90	-0.702	-0.719	-1.009	0.599	-0.929	-0.831	0.874	-0.458	-0.707	-0.921	-0.862	0.646	0.280
105	-0.321	-0.372	-0.569	0.915	-0.664	-0.587	1.334	-0.173	-0.416	-0.707	-0.618	1.115	0.548
120	-0.731	-0.587	-0.475	0.253	-0.612	-0.550	0.598	0.063	-0.266	-0.661	-0.599	0.426	0.075
135	-1.211	-0.949	-0.691	-0.275	-0.751	-0.678	0.143	0.158	-0.186	-0.802	-0.732	-0.005	-0.440
150	-1.264	-1.188	-1.013	-0.835	-0.858	-0.813	-0.548	0.476	0.218	-0.927	-0.877	-0.993	-0.746
165	-1.480	-1.526	-1.374	-1.291	-1.134	-1.109	-1.046	0.866	0.589	-1.196	-1.149	-1.702	-1.038
180	-1.762	-1.842	-1.645	-1.583	-1.613	-1.332	-1.420	0.821	0.716	-1.678	-1.340	-1.878	-1.248
195	-1.823	-1.879	-1.568	-1.508	-1.589	-1.138	-1.360	0.838	0.874	-1.593	-1.122	-1.576	-1.238
210	-1.899	-1.857	-1.230	-1.244	-0.513	-0.548	-1.088	0.672	0.959	-0.491	-0.554	-1.232	-1.054
225	-1.960	-1.961	-1.047	-1.085	0.363	0.015	-0.990	0.413	0.754	0.296	-0.022	-1.117	-0.941
240	-1.524	-2.014	-1.305	-1.092	0.940	0.576	-1.060	-0.051	0.086	0.846	0.484	-1.177	-1.027
255	-1.324	-1.737	-1.460	-0.948	1.292	1.049	-0.907	-0.409	-0.660	1.257	0.996	-0.996	-0.944
270	-1.080	-1.351	-1.234	-0.759	1.124	1.081	-0.730	-0.694	-0.937	1.094	1.055	-0.807	-0.763
285	-0.875	-1.187	-1.233	-0.765	0.724	1.118	-0.761	-0.834	-0.921	0.685	1.099	-0.873	-0.809
300	-0.602	-0.986	-1.184	-0.717	0.388	0.861	-0.634	-0.696	-0.777	0.351	0.858	-0.781	-0.712
315	-0.407	-0.859	-1.484	-0.806	-0.015	0.385	-0.720	-0.593	-0.658	-0.061	0.383	-0.806	-0.846
330	-0.381	-0.762	-1.561	-1.048	-0.384	-0.247	-0.843	-0.695	-0.681	-0.440	-0.238	-0.922	-0.908
345	-0.440	-0.513	-1.221	-1.400	-0.790	-0.948	-1.089	-0.806	-0.868	-0.788	-0.983	-1.106	-1.256

	Port 4 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**8A14**	**8A15**	**8B01**	**8B02**	**8C01**	**8C02**	**8C03**	**8C04**	**8C05**	**8C06**	**8C07**	**8C08**	**8C09**
0	-0.037	0.328	-1.406	-1.055	-1.020	-1.027	-1.053	-1.050	-1.068	-1.041	-1.018	-1.038	-0.891
15	0.370	0.692	-1.241	-0.957	-1.173	-1.199	-1.222	-1.188	-1.236	-1.147	-1.207	-1.108	-1.036
30	0.604	0.830	-0.919	-0.813	-1.263	-1.290	-1.302	-1.311	-1.332	-1.356	-1.422	-1.298	-1.255
45	0.710	0.890	-0.474	-0.497	-1.369	-1.374	-1.386	-1.356	-1.372	-1.385	-1.426	-1.368	-1.304
60	0.595	0.717	-0.109	-0.203	-1.566	-1.508	-1.532	-1.450	-1.466	-1.387	-1.411	-1.279	-1.190
75	0.595	0.630	0.565	0.428	-1.585	-1.404	-1.375	-1.253	-1.212	-1.138	-1.135	-1.026	-0.923
90	0.431	0.436	0.371	0.264	-0.885	-0.810	-0.752	-0.734	-0.647	-0.669	-0.603	-0.616	-0.440
105	-0.245	-0.243	-0.436	-0.511	-0.629	-0.613	-0.588	-0.550	-0.480	-0.513	-0.431	-0.431	-0.236
120	-0.657	-0.624	-0.615	-0.606	-0.684	-0.445	-0.449	-0.233	-0.199	-0.066	0.003	0.081	0.250
135	-1.223	-1.163	-0.650	-0.592	0.004	0.471	0.482	0.466	0.544	0.255	0.467	0.164	0.457
150	-1.146	-1.121	-0.785	-0.729	0.560	0.582	0.573	0.358	0.438	0.315	0.394	0.306	0.478
165	-1.206	-1.188	-1.450	-1.621	0.218	0.949	0.833	1.004	0.963	0.995	1.011	0.941	1.061
180	-1.146	-1.125	-1.457	-1.693	0.651	1.073	0.969	0.956	0.898	0.845	0.839	0.777	0.861
195	-1.188	-1.174	-1.365	-1.473	0.205	0.789	0.585	0.770	0.613	0.750	0.648	0.776	0.765
210	-1.191	-1.168	-1.262	-1.283	-0.163	0.520	0.257	0.549	0.350	0.591	0.430	0.631	0.566
225	-1.074	-1.066	-1.107	-1.122	-0.409	0.315	-0.002	0.324	0.063	0.396	0.140	0.437	0.258
240	-1.070	-1.032	-1.080	-1.095	-0.700	0.022	-0.301	0.059	-0.217	0.134	-0.101	0.148	0.033
255	-1.076	-1.053	-1.142	-1.235	-0.944	-0.220	-0.491	-0.168	-0.366	-0.172	-0.297	-0.185	-0.200
270	-0.737	-0.714	-0.790	-0.888	-0.733	-0.326	-0.451	-0.284	-0.367	-0.312	-0.404	-0.386	-0.345
285	-0.415	-0.381	-0.253	-0.247	-0.287	-0.279	-0.287	-0.309	-0.306	-0.391	-0.403	-0.472	-0.364
300	-0.542	-0.480	-0.442	-0.392	-0.340	-0.339	-0.334	-0.358	-0.336	-0.415	-0.405	-0.461	-0.336
315	-0.718	-0.576	-0.782	-0.694	-0.573	-0.533	-0.550	-0.498	-0.494	-0.505	-0.514	-0.514	-0.405
330	-0.538	-0.316	-1.023	-0.851	-0.701	-0.674	-0.695	-0.632	-0.633	-0.636	-0.648	-0.641	-0.533
345	-0.323	0.022	-1.261	-0.982	-0.800	-0.786	-0.801	-0.779	-0.775	-0.807	-0.818	-0.815	-0.708

	Port 5 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**8C10**	**8C11**	**8C12**	**8C13**	**8C14**	**8D01**	**8D02**	**8F01**	**8F02**	**7E01**	**7E02**	**7F01**	**7F02**
0	-0.968	-0.959	-0.987	-0.596	-1.044	-1.043	-1.019	-1.060	-1.206	-0.985	-0.971	-1.065	-1.108
15	-1.041	-1.046	-1.050	-0.666	-1.099	-1.108	-1.084	-1.098	-1.222	-1.010	-1.008	-1.108	-1.158
30	-1.155	-1.200	-1.086	-0.731	-1.048	-1.038	-1.002	-1.144	-1.156	-1.002	-1.001	-1.159	-1.074
45	-1.252	-1.299	-1.172	-0.842	-1.063	-0.955	-0.932	-1.105	-1.098	-0.866	-0.911	-1.147	-1.005
60	-1.192	-1.187	-1.142	-0.740	-1.188	-1.137	-0.929	-1.141	-1.039	-0.872	-0.767	-1.161	-0.931
75	-0.999	-0.962	-1.003	-0.557	-1.140	-1.265	-0.917	-1.000	-0.977	-1.013	-0.830	-0.995	-0.887
90	-0.616	-0.534	-0.714	-0.230	-1.024	-0.986	-0.665	-0.880	-0.791	-0.838	-0.685	-0.881	-0.705
105	-0.369	-0.292	-0.387	0.091	-0.682	-0.583	-0.349	-0.650	-0.565	-0.446	-0.411	-0.663	-0.468
120	0.180	0.228	0.107	0.598	-0.267	-0.254	-0.153	-0.607	-0.529	-0.241	-0.159	-0.606	-0.417
135	0.104	0.306	0.023	0.601	-0.327	-0.335	-0.245	-0.792	-0.694	-0.301	-0.283	-0.810	-0.570
150	0.358	0.452	0.344	0.826	0.039	-0.127	0.032	-0.893	-0.833	0.025	0.062	-0.957	-0.705
165	0.820	0.923	0.666	1.190	0.169	-0.081	0.149	-1.154	-1.133	0.126	0.161	-1.232	-0.961
180	0.734	0.805	0.672	1.150	0.426	0.076	0.350	-1.599	-1.379	0.270	0.348	-1.634	-1.199
195	0.804	0.783	0.822	1.209	0.687	0.311	0.672	-1.593	-1.210	0.529	0.598	-1.575	-1.102
210	0.705	0.595	0.745	1.037	0.793	0.601	0.923	-0.649	-0.651	0.776	0.720	-0.723	-0.647
225	0.593	0.383	0.541	0.730	0.818	0.804	1.022	0.178	-0.120	0.895	0.705	0.049	-0.186
240	0.179	0.032	-0.216	0.062	0.199	0.840	0.847	0.794	0.439	0.697	0.401	0.631	0.268
255	-0.351	-0.432	-0.804	-0.414	-0.187	1.065	0.853	1.134	0.845	0.561	0.034	0.855	0.519
270	-0.543	-0.574	-0.832	-0.437	-0.333	0.712	0.438	0.950	0.834	0.183	-0.311	0.680	0.552
285	-0.521	-0.527	-0.650	-0.274	-0.533	-0.516	-0.570	0.541	0.872	-0.610	-0.767	0.278	0.693
300	-0.472	-0.461	-0.526	-0.133	-0.573	-0.715	-0.694	0.264	0.669	-0.662	-0.728	0.066	0.527
315	-0.530	-0.513	-0.569	-0.175	-0.642	-0.638	-0.623	-0.040	0.278	-0.638	-0.597	-0.182	0.174
330	-0.626	-0.612	-0.667	-0.277	-0.757	-0.747	-0.727	-0.392	-0.303	-0.681	-0.679	-0.473	-0.262
345	-0.801	-0.792	-0.828	-0.444	-0.907	-0.901	-0.872	-0.786	-0.904	-0.870	-0.817	-0.816	-0.716

	Port 6 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**6C01**	**6C02**	**6C03**	**6C04**	**6C05**	**7C01**	**7C02**	**7C03**	**7C04**	**7C06**	**7C07**	**7C08**	**7D01**
0	-0.971	-0.977	-0.918	-0.600	-1.024	-0.958	-0.921	-0.930	-0.905	-0.935	-0.966	-1.029	-1.029
15	-1.092	-1.130	-1.103	-0.638	-1.039	-1.083	-1.079	-1.110	-1.063	-0.995	-1.002	-1.043	-1.086
30	-1.183	-1.214	-1.241	-0.737	-1.015	-1.193	-1.186	-1.219	-1.222	-1.112	-1.053	-1.012	-1.041
45	-1.269	-1.294	-1.277	-0.806	-1.042	-1.275	-1.258	-1.270	-1.275	-1.171	-1.115	-1.035	-0.937
60	-1.429	-1.471	-1.315	-0.791	-1.145	-1.444	-1.419	-1.399	-1.357	-1.191	-1.172	-1.160	-1.130
75	-1.382	-1.386	-1.174	-0.559	-1.464	-1.507	-1.384	-1.285	-1.270	-1.119	-1.140	-1.334	-1.434
90	-0.844	-0.689	-0.436	-0.152	-1.212	-1.014	-0.766	-0.675	-0.584	-0.590	-0.693	-1.176	-1.158
105	-0.559	-0.506	-0.377	0.118	-0.668	-0.575	-0.503	-0.473	-0.433	-0.295	-0.315	-0.711	-0.685
120	-0.575	-0.367	0.035	0.522	-0.345	-0.601	-0.327	-0.148	-0.005	0.188	0.127	-0.342	-0.320
135	-0.080	0.440	0.434	0.476	-0.421	-0.032	0.494	0.468	0.315	0.148	0.025	-0.373	-0.363
150	0.266	0.479	0.416	0.781	0.022	0.394	0.594	0.399	0.369	0.430	0.401	0.035	-0.065
165	-0.131	0.681	1.026	1.168	0.107	0.018	0.908	1.030	1.091	0.946	0.796	0.129	0.052
180	0.469	1.031	1.003	1.170	0.353	0.646	1.249	1.170	1.055	0.896	0.845	0.403	0.193
195	0.096	0.685	0.825	1.211	0.527	0.251	0.962	0.966	0.939	0.990	0.979	0.638	0.380
210	-0.317	0.351	0.650	0.980	0.537	-0.194	0.678	0.764	0.792	0.843	0.832	0.734	0.589
225	-0.589	0.040	0.304	0.713	0.524	-0.473	0.383	0.450	0.471	0.636	0.574	0.763	0.750
240	-0.856	-0.223	0.083	0.207	0.072	-0.797	0.060	0.160	0.186	0.211	-0.110	0.185	0.818
255	-0.929	-0.392	-0.202	-0.297	-0.238	-0.967	-0.223	-0.151	-0.169	-0.334	-0.680	-0.155	0.961
270	-0.686	-0.364	-0.317	-0.391	-0.346	-0.727	-0.250	-0.241	-0.294	-0.511	-0.746	-0.261	0.603
285	-0.273	-0.249	-0.345	-0.252	-0.550	-0.277	-0.231	-0.278	-0.354	-0.508	-0.616	-0.518	-0.561
300	-0.305	-0.293	-0.346	-0.130	-0.541	-0.300	-0.294	-0.326	-0.382	-0.460	-0.493	-0.545	-0.727
315	-0.539	-0.516	-0.473	-0.191	-0.627	-0.531	-0.502	-0.481	-0.488	-0.512	-0.555	-0.610	-0.653
330	-0.671	-0.655	-0.593	-0.296	-0.752	-0.649	-0.630	-0.600	-0.599	-0.611	-0.658	-0.727	-0.730
345	-0.730	-0.728	-0.710	-0.444	-0.868	-0.731	-0.682	-0.723	-0.710	-0.781	-0.788	-0.886	-0.862

	Port 7 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**6A01**	**6A02**	**6A03**	**6A04**	**6A05**	**7A01**	**7A02**	**7A03**	**7A04**	**7A05**	**7A06**	**7C05**	**00J01**
0	0.077	0.637	0.926	1.110	0.243	0.762	0.837	0.979	1.012	1.034	0.143	-0.917	-1.431
15	-0.173	0.566	0.770	0.939	0.693	0.664	0.693	0.841	0.888	1.033	0.621	-1.047	-1.512
30	-0.252	0.548	0.715	0.814	0.871	0.622	0.633	0.755	0.791	0.922	0.833	-1.192	-1.623
45	-0.204	0.516	0.593	0.616	0.933	0.567	0.541	0.572	0.644	0.630	0.943	-1.276	-1.545
60	-0.045	0.487	0.503	0.484	0.727	0.531	0.482	0.446	0.470	0.391	0.747	-1.274	-1.407
75	-0.028	0.507	0.454	0.398	0.692	0.538	0.454	0.405	0.419	0.091	0.717	-1.187	-1.507
90	0.132	0.575	0.468	0.386	0.603	0.592	0.499	0.427	0.418	0.186	0.618	-0.570	-1.507
105	0.105	0.278	0.214	0.111	0.045	0.242	0.211	0.160	0.102	0.031	-0.058	-0.341	-1.305
120	-0.132	-0.100	-0.118	-0.243	-0.433	-0.140	-0.120	-0.176	-0.240	-0.301	-0.505	0.123	-1.099
135	-0.475	-0.517	-0.512	-0.599	-0.845	-0.539	-0.519	-0.544	-0.592	-0.614	-0.963	0.274	-1.464
150	-0.694	-0.724	-0.744	-0.878	-1.223	-0.761	-0.740	-0.859	-0.891	-0.862	-1.258	0.367	-1.455
165	-0.832	-0.837	-0.854	-0.983	-1.066	-0.845	-0.805	-0.963	-0.996	-1.012	-1.067	1.061	-1.650
180	-0.946	-0.920	-0.827	-0.944	-1.081	-0.915	-0.841	-0.915	-0.983	-0.993	-1.089	0.958	-1.821
195	-0.972	-0.957	-0.874	-0.994	-1.148	-0.920	-0.867	-0.961	-1.038	-1.049	-1.159	0.961	-1.700
210	-0.960	-0.968	-0.911	-1.007	-1.121	-0.935	-0.901	-0.976	-1.039	-1.045	-1.143	0.814	-1.492
225	-0.851	-0.880	-0.816	-0.883	-1.001	-0.851	-0.822	-0.839	-0.901	-0.914	-1.014	0.571	-1.426
240	-0.871	-0.998	-0.900	-0.896	-0.987	-0.949	-0.912	-0.870	-0.901	-0.901	-1.014	0.260	-1.144
255	-0.751	-0.939	-0.770	-0.806	-0.886	-0.875	-0.809	-0.753	-0.811	-0.818	-0.929	-0.139	-0.657
270	-0.549	-0.741	-0.576	-0.575	-0.693	-0.695	-0.608	-0.551	-0.569	-0.599	-0.669	-0.359	-0.349
285	-0.511	-0.778	-0.543	-0.420	-0.307	-0.733	-0.614	-0.475	-0.425	-0.326	-0.376	-0.407	-0.158
300	-0.434	-0.630	-0.187	-0.005	-0.437	-0.543	-0.348	-0.052	-0.032	-0.023	-0.497	-0.411	-0.055
315	-0.165	-0.110	0.489	0.447	-0.698	0.033	0.404	0.433	0.362	0.308	-0.677	-0.462	-0.179
330	0.112	0.242	0.575	0.661	-0.497	0.355	0.563	0.612	0.622	0.577	-0.497	-0.583	-0.463
345	0.305	0.494	0.798	0.952	-0.102	0.597	0.722	0.884	0.892	0.896	-0.196	-0.746	-1.036

	Port 8 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**1A01**	**1A02**	**1A03**	**1A04**	**2A01**	**2C01**	**2C02**	**2C03**	**2C04**	**2C05**	**3A01**	**3A02**	**3A03**
0	0.646	0.827	0.873	0.131	0.149	-0.943	-0.953	-0.914	-0.926	-0.963	0.829	0.909	0.173
15	0.626	0.866	0.892	0.500	0.578	-1.067	-1.086	-1.053	-0.954	-0.950	0.885	0.909	0.615
30	0.606	0.874	0.852	0.641	0.736	-1.188	-1.213	-1.199	-1.102	-1.032	0.898	0.871	0.790
45	0.595	0.796	0.736	0.656	0.804	-1.247	-1.258	-1.258	-1.117	-0.983	0.851	0.718	0.854
60	0.590	0.723	0.634	0.435	0.611	-1.343	-1.309	-1.141	-0.905	-0.574	0.778	0.659	0.657
75	0.550	0.612	0.535	0.351	0.511	-1.043	-0.925	-0.321	-0.181	-0.215	0.673	0.554	0.571
90	0.579	0.583	0.524	0.365	0.477	-0.463	-0.400	-0.169	-0.127	-0.129	0.655	0.536	0.551
105	0.364	0.356	0.281	0.069	0.083	-0.471	-0.466	-0.344	-0.171	-0.018	0.362	0.248	0.096
120	0.053	0.011	-0.091	-0.205	-0.215	-0.469	-0.294	-0.007	0.166	0.158	0.033	-0.120	-0.288
135	-0.389	-0.457	-0.522	-0.649	-0.657	-0.240	0.299	0.413	0.214	0.029	-0.442	-0.515	-0.677
150	-0.575	-0.699	-0.812	-0.866	-1.027	-0.121	0.465	0.423	0.343	0.230	-0.643	-0.865	-1.028
165	-0.752	-0.827	-0.965	-0.994	-1.030	-0.304	0.567	0.871	0.740	0.424	-0.801	-0.934	-1.043
180	-0.844	-0.901	-0.954	-1.009	-1.027	-0.100	0.787	0.848	0.696	0.428	-0.881	-0.886	-1.020
195	-0.892	-0.954	-1.013	-1.105	-1.116	-0.254	0.557	0.747	0.740	0.495	-0.907	-0.941	-1.100
210	-0.895	-0.949	-1.001	-1.081	-1.092	-0.355	0.322	0.573	0.595	0.394	-0.904	-0.962	-1.079
225	-0.761	-0.819	-0.874	-0.947	-0.956	-0.430	0.083	0.330	0.461	0.300	-0.784	-0.823	-0.939
240	-0.708	-0.822	-0.858	-0.892	-0.931	-0.511	-0.075	0.153	0.179	-0.032	-0.802	-0.847	-0.913
255	-0.518	-0.661	-0.804	-0.842	-0.919	-0.496	-0.164	-0.031	-0.119	-0.370	-0.660	-0.752	-0.913
270	-0.307	-0.428	-0.499	-0.597	-0.726	-0.294	-0.155	-0.137	-0.279	-0.488	-0.424	-0.475	-0.729
285	-0.231	-0.343	-0.156	-0.071	-0.107	-0.105	-0.123	-0.231	-0.388	-0.574	-0.387	-0.324	-0.146
300	-0.018	-0.071	0.129	-0.118	-0.166	-0.250	-0.225	-0.294	-0.410	-0.576	-0.155	-0.028	-0.235
315	0.330	0.262	0.352	-0.391	-0.462	-0.485	-0.479	-0.436	-0.502	-0.574	0.160	0.292	-0.567
330	0.439	0.359	0.405	-0.276	-0.373	-0.620	-0.604	-0.577	-0.634	-0.683	0.310	0.369	-0.454
345	0.579	0.655	0.727	-0.006	-0.031	-0.745	-0.748	-0.763	-0.824	-0.859	0.648	0.743	-0.044

	Port 9 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**3B01**	**3B02**	**3C01**	**3C02**	**4A01**	**4C01**	**4C02**	**4C04**	**4C05**	**5A01**	**5A02**	**5A03**	**5B01**
0	-1.364	-0.986	-0.962	-0.953	0.156	-0.951	-0.953	-0.888	-0.983	0.957	1.080	0.137	-1.257
15	-1.083	-0.838	-1.123	-0.966	0.566	-1.107	-1.126	-0.963	-1.016	0.924	1.034	0.588	-1.049
30	-0.652	-0.583	-1.230	-1.018	0.809	-1.218	-1.233	-1.138	-1.039	0.851	0.932	0.866	-0.651
45	-0.269	-0.368	-1.334	-0.967	0.926	-1.354	-1.340	-1.220	-1.025	0.690	0.725	0.951	-0.093
60	0.142	-0.121	-1.472	-0.510	0.868	-1.466	-1.465	-1.021	-0.777	0.636	0.602	0.893	0.290
75	0.165	-0.038	-1.384	-0.475	0.744	-1.379	-1.313	-0.387	-1.017	0.569	0.512	0.787	0.406
90	0.116	0.060	-0.703	-0.364	0.619	-0.722	-0.598	-0.263	-0.779	0.541	0.495	0.629	0.180
105	-0.368	-0.352	-0.541	-0.062	0.101	-0.566	-0.542	-0.249	-0.304	0.243	0.161	0.073	-0.426
120	-0.623	-0.577	-0.598	0.041	-0.338	-0.613	-0.416	0.156	-0.127	-0.094	-0.222	-0.377	-0.567
135	-0.672	-0.862	0.005	-0.130	-1.115	0.255	0.792	0.363	-0.368	-0.505	-0.728	-1.213	-0.809
150	-0.936	-1.091	0.128	0.115	-1.073	0.236	0.491	0.383	0.049	-0.735	-0.885	-1.137	-0.905
165	-1.303	-1.467	-0.757	0.169	-1.076	-0.488	0.443	0.811	0.158	-0.854	-0.971	-1.067	-1.318
180	-1.321	-1.479	-0.429	0.251	-1.079	-0.061	0.690	0.724	0.267	-0.853	-0.979	-1.081	-1.349
195	-1.285	-1.416	-0.688	0.333	-1.141	-0.410	0.369	0.737	0.356	-0.891	-1.017	-1.140	-1.301
210	-1.209	-1.312	-0.772	0.234	-1.103	-0.609	0.158	0.578	0.247	-0.912	-1.009	-1.100	-1.216
225	-1.022	-1.087	-0.821	0.101	-0.962	-0.788	-0.072	0.369	0.088	-0.793	-0.884	-0.963	-1.043
240	-0.945	-1.028	-0.858	-0.246	-0.909	-0.907	-0.269	0.109	-0.316	-0.819	-0.836	-0.906	-0.970
255	-0.848	-0.987	-0.745	-0.620	-0.932	-0.822	-0.341	-0.286	-0.687	-0.687	-0.797	-0.871	-0.871
270	-0.402	-0.454	-0.383	-0.620	-0.756	-0.482	-0.267	-0.439	-0.666	-0.499	-0.524	-0.723	-0.643
285	-0.055	-0.074	-0.140	-0.640	-0.252	-0.154	-0.153	-0.475	-0.622	-0.493	-0.369	-0.281	-0.142
300	-0.405	-0.307	-0.276	-0.635	-0.360	-0.296	-0.264	-0.399	-0.606	-0.160	-0.019	-0.380	-0.402
315	-0.704	-0.549	-0.501	-0.594	-0.612	-0.510	-0.486	-0.449	-0.608	0.404	0.363	-0.650	-0.723
330	-0.947	-0.713	-0.676	-0.715	-0.487	-0.650	-0.622	-0.591	-0.729	0.491	0.561	-0.510	-0.933
345	-1.245	-0.863	-0.783	-0.882	-0.122	-0.752	-0.743	-0.782	-0.892	0.846	0.973	-0.141	-1.167

	Port 10 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**5B02**	**5C01**	**5C02**	**5C03**	**5C04**	**5D01**	**5F01**	**5F02**	**6D01**	**6D02**	**6F01**	**6F02**	**7B01**
0	-1.059	-1.024	-1.013	-0.936	-1.062	-1.073	-1.152	-0.925	-1.084	-1.078	-1.133	-1.274	-1.201
15	-0.955	-1.172	-1.206	-1.114	-1.093	-1.134	-1.156	-1.080	-1.159	-1.088	-1.154	-1.242	-0.623
30	-0.697	-1.278	-1.320	-1.282	-1.084	-1.101	-1.232	-1.218	-1.110	-1.057	-1.234	-1.261	-0.088
45	-0.299	-1.354	-1.364	-1.328	-1.116	-1.018	-1.157	-1.214	-1.022	-0.945	-1.200	-1.179	0.458
60	-0.131	-1.507	-1.407	-1.216	-1.073	-1.142	-1.059	-1.139	-1.223	-0.776	-1.127	-1.086	0.616
75	0.086	-1.306	-1.069	-0.766	-1.185	-1.369	-1.082	-1.004	-1.415	-0.815	-0.999	-0.956	0.953
90	-0.145	-0.738	-0.514	-0.406	-0.967	-1.100	-0.787	-0.849	-1.155	-0.735	-0.888	-0.811	0.613
105	-0.565	-0.621	-0.506	-0.331	-0.547	-0.618	-0.545	-0.613	-0.742	-0.449	-0.678	-0.604	-0.155
120	-0.633	-0.662	-0.202	0.091	-0.278	-0.350	-0.551	-0.547	-0.403	-0.202	-0.610	-0.550	-0.495
135	-1.011	-0.242	0.466	0.297	-0.458	-0.558	-0.686	-0.673	-0.558	-0.303	-0.806	-0.677	-0.551
150	-1.212	0.098	0.375	0.393	0.025	-0.084	-0.623	-0.739	-0.112	0.042	-0.952	-0.769	-0.443
165	-1.573	-0.231	0.910	0.965	0.136	0.007	-0.773	-0.888	-0.009	0.134	-1.211	-0.952	-1.195
180	-1.554	0.212	0.909	0.856	0.331	0.158	-0.794	-1.020	0.153	0.255	-1.404	-1.099	-1.219
195	-1.389	-0.200	0.645	0.826	0.477	0.332	-0.688	-1.003	0.352	0.439	-1.228	-1.064	-1.199
210	-1.281	-0.470	0.422	0.576	0.375	0.459	-0.281	-0.686	0.547	0.697	-0.479	-0.738	-1.165
225	-1.125	-0.718	0.102	0.262	0.284	0.514	0.051	-0.327	0.666	0.799	0.063	-0.376	-1.054
240	-1.097	-0.941	-0.140	0.047	-0.130	0.551	0.291	0.020	0.756	0.749	0.446	-0.087	-1.057
255	-1.095	-0.945	-0.240	-0.207	-0.380	0.546	0.388	0.287	0.845	0.679	0.572	0.172	-1.019
270	-0.817	-0.638	-0.314	-0.409	-0.446	-0.051	0.163	0.259	0.165	0.032	0.218	0.255	-0.704
285	-0.217	-0.246	-0.285	-0.453	-0.597	-0.718	-0.084	0.219	-0.703	-0.694	-0.082	0.319	-0.263
300	-0.372	-0.325	-0.331	-0.424	-0.580	-0.745	-0.208	0.053	-0.758	-0.730	-0.209	0.151	-0.500
315	-0.652	-0.541	-0.476	-0.491	-0.618	-0.662	-0.369	-0.154	-0.670	-0.649	-0.361	-0.171	-0.877
330	-0.795	-0.690	-0.625	-0.628	-0.759	-0.748	-0.616	-0.412	-0.777	-0.754	-0.605	-0.628	-1.136
345	-0.897	-0.788	-0.767	-0.792	-0.909	-0.903	-0.917	-0.597	-0.928	-0.889	-0.893	-0.786	-1.271

	Port 11 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**0C01**	**0B02**	**0B01**	**0A04**	**0RR1**	**0RR2**	**0RR3**	**0RR4**	**0RR5**	**0RR6**	**0RR7**	**0RR8**	**0D01**
0	-0.789	-1.100	-1.554	-2.160	-1.835	-1.833	-1.549	-1.466	-1.240	-1.187	-0.946	-0.977	-0.995
15	-0.794	-1.212	-1.783	-2.711	-2.191	-2.197	-1.381	-1.672	-1.088	-1.326	-0.900	-1.112	-1.062
30	-0.996	-1.458	-2.222	-2.960	-2.177	-2.326	-1.318	-2.031	-1.222	-1.537	-1.086	-1.359	-1.074
45	-1.163	-1.666	-2.609	-2.890	-1.902	-2.471	-1.366	-2.242	-1.345	-1.742	-1.224	-1.545	-0.955
60	-1.192	-1.672	-2.477	-2.396	-1.447	-2.410	-1.333	-2.032	-1.243	-1.726	-1.175	-1.582	-0.764
75	-0.773	-1.191	-1.718	-1.477	-0.808	-1.995	-0.938	-1.425	-0.646	-1.268	-0.645	-1.253	-0.303
90	-0.021	-0.159	-0.504	-0.309	-0.061	-0.641	-0.052	-0.336	0.065	-0.277	0.044	-0.412	0.030
105	-0.231	-0.126	0.019	0.144	0.094	0.058	0.071	0.012	0.003	-0.114	-0.133	-0.281	0.226
120	-0.398	-0.333	-0.233	-0.119	-0.175	-0.193	-0.182	-0.244	-0.216	-0.349	-0.296	-0.404	0.122
135	-0.825	-0.373	-0.289	-0.057	-0.263	-0.195	-0.256	-0.330	-0.298	-0.385	-0.565	-0.527	-0.222
150	-1.685	-0.555	-0.398	-0.043	-0.340	-0.343	-0.410	-0.454	-0.523	-0.548	-1.104	-1.071	-0.621
165	-2.195	-1.103	-0.773	-0.504	-0.728	-0.749	-0.893	-0.883	-1.107	-1.031	-1.671	-1.526	-1.177
180	-2.349	-1.387	-0.994	-0.766	-0.961	-0.950	-1.167	-1.099	-1.440	-1.298	-1.853	-1.887	-0.993
195	-2.090	-1.429	-1.119	-1.035	-1.128	-1.080	-1.270	-1.216	-1.439	-1.361	-1.698	-1.690	-0.726
210	-1.924	-1.307	-0.992	-0.938	-1.047	-0.925	-1.184	-1.107	-1.316	-1.221	-1.548	-1.473	-0.681
225	-1.666	-1.035	-0.689	-0.623	-0.774	-0.600	-0.892	-0.833	-1.029	-0.941	-1.239	-1.101	-1.050
240	-1.353	-0.890	-0.510	-0.504	-0.647	-0.455	-0.700	-0.677	-0.823	-0.777	-1.028	-0.874	-1.678
255	-0.878	-0.681	-0.447	-0.530	-0.607	-0.442	-0.570	-0.568	-0.590	-0.580	-0.728	-0.619	-1.414
270	-0.508	-0.485	-0.416	-0.509	-0.552	-0.435	-0.493	-0.468	-0.448	-0.441	-0.455	-0.373	-1.042
285	-0.226	-0.228	-0.259	-0.341	-0.376	-0.287	-0.317	-0.252	-0.261	-0.216	-0.231	-0.176	-0.818
300	-0.247	-0.304	-0.328	-0.653	-0.476	-0.367	-0.377	-0.337	-0.320	-0.310	-0.292	-0.255	-0.682
315	-0.255	-0.428	-0.654	-1.328	-0.949	-0.812	-0.619	-0.624	-0.451	-0.509	-0.320	-0.315	-0.577
330	-0.509	-0.664	-0.960	-1.606	-1.273	-1.143	-0.944	-0.856	-0.719	-0.738	-0.569	-0.561	-0.700
345	-0.714	-0.952	-1.313	-1.892	-1.571	-1.510	-1.334	-1.221	-1.082	-0.996	-0.838	-0.819	-0.870

	Port 12 Mean Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**0RL1**	**0RL2**	**0RL3**	**0RL4**	**0RL5**	**0RL6**	**0RL7**	**0RL8**	**0RL13**	**0RL12**	**0RL11**	**0RL10**	**0RL9**
0	-1.607	-1.492	-1.376	-1.383	-1.226	-1.313	-1.006	-1.164	-1.118	-1.110	-1.166	-1.549	-1.448
15	-1.570	-1.491	-1.420	-1.443	-1.300	-1.371	-1.122	-1.237	-1.205	-1.200	-1.219	-1.589	-1.569
30	-1.620	-1.547	-1.479	-1.512	-1.342	-1.435	-1.174	-1.290	-1.244	-1.263	-1.239	-1.647	-1.611
45	-1.477	-1.424	-1.303	-1.351	-1.181	-1.243	-1.025	-1.104	-1.097	-1.109	-1.194	-1.494	-1.454
60	-1.231	-1.202	-1.066	-1.121	-1.026	-1.045	-0.903	-0.922	-0.993	-1.026	-1.148	-1.236	-1.190
75	-0.606	-0.658	-0.449	-0.556	-0.527	-0.504	-0.480	-0.502	-0.642	-0.801	-1.085	-0.612	-0.466
90	0.177	0.114	0.373	0.228	0.126	0.118	-0.037	-0.054	-0.244	-0.372	-1.012	0.150	0.308
105	0.411	0.345	0.596	0.432	0.356	0.300	0.174	0.117	0.023	0.039	-0.384	0.322	0.448
120	0.048	0.038	0.162	0.079	0.086	0.015	0.013	-0.109	-0.041	0.059	0.159	-0.134	-0.046
135	-0.370	-0.347	-0.302	-0.331	-0.302	-0.378	-0.388	-0.546	-0.403	-0.097	0.315	-0.681	-0.662
150	-0.663	-0.619	-0.720	-0.696	-0.755	-0.820	-0.843	-0.958	-0.888	-0.296	0.260	-0.899	-0.784
165	-0.910	-0.825	-1.044	-1.049	-1.272	-1.480	-1.520	-1.637	-1.480	-0.434	0.489	-1.253	-1.102
180	-1.221	-0.989	-1.259	-1.118	-1.230	-1.603	-1.861	-1.970	-1.688	-0.598	0.130	-1.450	-1.269
195	-1.382	-1.176	-1.285	-1.099	-0.993	-1.389	-1.868	-2.180	-1.432	-0.569	-0.114	-1.371	-1.219
210	-1.256	-1.191	-1.196	-1.063	-0.775	-0.958	-1.281	-1.601	-0.781	-0.663	-0.634	-1.164	-1.077
225	-1.103	-1.039	-1.127	-1.017	-0.761	-0.766	-0.902	-1.092	-0.572	-0.942	-1.010	-1.106	-1.022
240	-1.070	-0.951	-1.128	-0.977	-1.009	-0.893	-0.807	-0.871	-0.962	-1.247	-1.463	-1.199	-1.110
255	-0.942	-0.903	-0.963	-0.863	-0.934	-0.851	-0.832	-0.719	-1.264	-1.098	-1.596	-1.141	-1.006
270	-0.736	-0.740	-0.752	-0.679	-0.715	-0.640	-0.664	-0.590	-0.965	-0.803	-1.229	-0.937	-0.786
285	-0.780	-0.762	-0.802	-0.717	-0.798	-0.687	-0.649	-0.591	-0.801	-0.838	-0.932	-0.999	-0.866
300	-0.743	-0.731	-0.725	-0.680	-0.724	-0.646	-0.615	-0.585	-0.714	-0.748	-0.783	-0.884	-0.767
315	-0.951	-1.016	-0.752	-0.728	-0.691	-0.613	-0.560	-0.537	-0.672	-0.721	-0.755	-0.960	-0.880
330	-1.174	-1.407	-0.913	-0.895	-0.789	-0.707	-0.603	-0.576	-0.767	-0.826	-0.917	-1.033	-1.011
345	-1.574	-1.560	-1.248	-1.296	-1.056	-1.096	-0.798	-0.888	-0.906	-0.935	-1.078	-1.280	-1.129

	Port 1 Negative Peak Pressure Coefficients												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**8A01**	**8A02**	**8A03**	**8A04**	**8A05**	**8A06**	**8A07**	**8A08**	**8A09**	**8A10**	**8A11**	**8A12**	**8A13**
0	-1.357	-1.311	-1.458	-1.416	-1.541	-1.324	-1.731	-1.486	-1.586	-1.448	-1.516	-1.824	-1.512
15	-1.723	-1.533	-1.898	-1.666	-1.738	-1.145	-1.960	-1.560	-1.559	-1.673	-1.678	-1.868	-1.583
30	-1.704	-1.740	-1.922	-1.956	-1.785	-1.344	-1.999	-1.927	-1.792	-1.629	-1.822	-2.232	-2.223
45	-1.637	-1.459	-1.717	-1.980	-1.801	-1.410	-1.735	-1.676	-1.734	-1.555	-1.777	-2.686	-2.324
60	-1.462	-1.295	-1.498	-1.437	-1.470	-1.291	-1.388	-1.565	-1.503	-1.552	-1.762	-2.563	-2.371
75	-1.399	-1.085	-1.114	-1.236	-1.259	-1.115	-1.182	-1.417	-1.324	-1.468	-1.426	-2.093	-1.904
90	-1.609	-0.963	-0.688	-0.984	-0.857	-0.792	-0.875	-0.924	-0.935	-0.980	-1.034	-1.469	-1.200
105	-2.270	-4.685	-2.570	-2.258	-1.631	-2.328	-1.597	-1.990	-1.243	-2.134	-1.294	-2.581	-1.410
120	-2.405	-3.960	-4.214	-2.408	-1.694	-1.970	-1.590	-3.204	-1.920	-3.278	-2.148	-3.042	-1.967
135	-1.972	-2.732	-2.747	-1.775	-1.625	-1.651	-1.574	-2.772	-1.831	-2.726	-1.891	-2.744	-2.024
150	-1.915	-2.236	-2.181	-1.770	-1.772	-1.947	-1.851	-2.461	-1.988	-2.491	-2.156	-2.075	-1.915
165	-2.058	-2.028	-2.030	-1.909	-1.934	-2.162	-2.010	-2.412	-2.090	-2.999	-2.156	-2.240	-2.015
180	-2.233	-2.239	-2.190	-2.071	-2.043	-2.058	-2.111	-2.184	-2.100	-2.338	-2.151	-2.209	-2.029
195	-2.141	-2.082	-2.062	-2.111	-2.046	-2.101	-2.113	-2.160	-2.183	-2.253	-2.265	-2.333	-2.107
210	-1.907	-1.910	-1.932	-1.910	-1.911	-2.039	-2.002	-2.162	-2.099	-2.184	-2.136	-2.175	-2.033
225	-1.713	-1.816	-1.800	-1.851	-1.931	-1.992	-1.974	-1.984	-1.944	-2.136	-2.069	-2.186	-1.946
240	-1.669	-1.928	-1.929	-2.094	-2.559	-2.359	-3.265	-2.394	-2.987	-2.270	-2.392	-2.488	-2.408
255	-1.617	-1.894	-1.865	-1.887	-2.230	-1.951	-2.251	-2.258	-2.320	-2.429	-2.672	-2.549	-2.614
270	-1.407	-1.740	-1.736	-1.806	-1.706	-1.717	-1.874	-1.838	-1.905	-1.943	-2.227	-1.943	-2.220
285	-1.343	-1.838	-1.821	-1.971	-1.970	-1.990	-2.149	-2.022	-2.155	-2.084	-2.564	-1.969	-2.224
300	-1.365	-2.034	-2.108	-1.889	-1.937	-2.097	-2.331	-2.087	-2.201	-2.065	-2.226	-1.801	-1.867
315	-1.307	-1.879	-1.869	-1.608	-2.080	-1.525	-1.646	-1.857	-1.561	-2.189	-1.575	-2.197	-1.894
330	-1.369	-1.715	-1.774	-1.519	-1.706	-1.420	-1.589	-1.974	-1.507	-1.797	-1.399	-1.777	-1.448
345	-1.163	-1.506	-1.846	-1.397	-1.627	-1.316	-1.526	-1.613	-1.750	-1.357	-1.435	-1.954	-1.309

	Port 2 Negative Peak Pressure Coefficients												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**0A03**	**0C02**	**0A02**	**0C03**	**0RM1**	**0RM2**	**0RM3**	**0RM4**	**0RM5**	**0RM6**	**0RM7**	**0RM8**	**0RM9**
0	-5.433	-2.919	-4.709	-3.280	-4.310	-4.275	-3.688	-3.893	-3.932	-3.453	-3.407	-3.173	-3.745
15	-5.737	-2.662	-4.618	-3.471	-4.840	-4.733	-3.849	-4.100	-3.588	-3.485	-3.536	-3.139	-4.001
30	-5.445	-2.773	-5.314	-3.064	-5.173	-4.899	-3.934	-3.903	-3.523	-3.487	-3.123	-2.911	-3.933
45	-5.520	-2.073	-5.800	-2.630	-4.863	-4.680	-3.601	-3.831	-3.421	-3.413	-2.806	-2.572	-3.551
60	-5.100	-2.106	-5.008	-2.637	-4.302	-4.005	-3.490	-3.561	-3.484	-3.228	-2.636	-2.523	-3.554
75	-3.797	-1.784	-3.327	-1.650	-3.103	-3.248	-2.748	-2.683	-2.108	-1.903	-1.736	-1.575	-2.521
90	-2.573	-1.221	-2.073	-1.357	-1.708	-1.975	-1.404	-1.378	-1.341	-1.392	-1.200	-1.171	-1.328
105	-1.256	-1.948	-1.606	-1.534	-1.302	-1.093	-1.105	-1.189	-1.346	-1.270	-1.367	-1.480	-1.208
120	-1.544	-2.924	-1.668	-3.450	-1.433	-1.387	-1.730	-1.700	-1.887	-1.911	-2.533	-2.726	-1.966
135	-1.667	-4.306	-1.451	-3.623	-1.577	-1.576	-1.795	-1.819	-2.147	-2.121	-2.975	-3.428	-1.910
150	-1.762	-4.722	-1.705	-5.064	-2.425	-2.112	-2.435	-2.232	-2.625	-2.562	-3.523	-3.813	-2.326
165	-2.514	-6.536	-2.536	-6.331	-2.785	-2.805	-3.373	-3.234	-3.675	-3.682	-5.175	-5.710	-3.669
180	-2.937	-4.896	-3.217	-5.900	-3.221	-2.853	-3.545	-3.427	-3.702	-3.860	-4.768	-4.817	-3.873
195	-2.764	-5.095	-3.436	-6.162	-2.901	-2.846	-3.423	-3.412	-4.025	-3.767	-4.926	-5.099	-3.549
210	-2.730	-5.255	-4.502	-6.496	-3.181	-2.973	-3.605	-3.529	-4.326	-4.326	-5.144	-5.300	-4.087
225	-2.202	-4.958	-3.681	-5.226	-3.420	-2.368	-2.628	-2.711	-3.443	-3.410	-3.942	-4.331	-2.947
240	-2.106	-4.558	-2.700	-4.306	-2.543	-2.170	-2.219	-2.022	-2.503	-2.529	-3.063	-3.527	-2.246
255	-2.193	-3.329	-2.495	-3.148	-2.250	-2.096	-2.063	-1.932	-1.927	-1.905	-2.320	-2.346	-1.897
270	-2.693	-2.473	-2.752	-2.629	-2.774	-2.474	-2.259	-2.141	-1.915	-1.883	-2.059	-2.066	-2.051
285	-3.138	-1.949	-2.582	-2.452	-3.405	-2.548	-2.341	-2.298	-2.505	-2.196	-2.120	-2.004	-2.353
300	-4.027	-2.554	-3.140	-2.289	-3.059	-2.966	-2.216	-2.177	-2.121	-2.186	-2.225	-2.373	-2.116
315	-4.910	-1.663	-4.236	-1.597	-4.161	-3.621	-2.657	-2.875	-2.092	-2.116	-1.691	-1.854	-2.599
330	-5.061	-2.110	-4.483	-1.744	-4.315	-4.552	-3.025	-3.184	-2.692	-2.729	-2.005	-2.193	-2.893
345	-5.133	-2.774	-4.546	-2.656	-4.595	-4.536	-3.552	-3.723	-3.189	-3.145	-2.838	-2.788	-3.441

	Port 3 Negative Peak Pressure Coefficients												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**00K01**	**00L01**	**00L02**	**9J01**	**9L01**	**9L02**	**10J01**	**10K01**	**10K02**	**10L01**	**10L02**	**10J02**	**0A01**
0	-2.881	-2.913	-4.114	-4.685	-2.833	-3.914	-4.823	-2.035	-2.141	-2.940	-4.271	-3.451	-5.593
15	-4.035	-3.213	-3.429	-4.639	-2.910	-3.171	-4.941	-2.392	-2.483	-3.076	-4.183	-4.218	-4.528
30	-4.044	-3.622	-3.946	-5.347	-2.554	-2.858	-4.857	-2.522	-2.690	-3.019	-3.262	-4.367	-5.498
45	-3.724	-3.890	-3.615	-4.642	-2.574	-2.464	-4.572	-2.478	-2.904	-2.938	-2.759	-3.545	-4.929
60	-3.408	-3.418	-3.577	-4.045	-2.700	-2.302	-4.348	-2.106	-2.188	-2.731	-2.405	-3.236	-4.634
75	-3.373	-3.114	-3.414	-2.992	-2.914	-2.141	-3.494	-2.247	-2.605	-2.632	-2.295	-2.792	-3.521
90	-2.908	-2.253	-2.764	-1.506	-2.195	-1.853	-1.570	-2.026	-2.193	-2.192	-1.958	-1.523	-1.819
105	-2.557	-1.922	-1.981	-1.077	-1.831	-1.634	-0.667	-1.917	-1.958	-1.900	-1.759	-0.898	-1.105
120	-3.370	-2.900	-2.106	-1.420	-1.862	-1.596	-1.273	-1.348	-1.612	-1.896	-1.704	-2.434	-1.695
135	-3.875	-3.731	-2.684	-2.478	-2.050	-1.835	-2.383	-1.682	-1.623	-2.327	-2.153	-3.445	-2.403
150	-4.439	-4.247	-4.074	-3.583	-2.988	-2.465	-3.587	-1.911	-1.733	-3.324	-2.701	-5.133	-3.083
165	-4.081	-4.500	-4.062	-5.064	-3.438	-3.315	-4.499	-1.733	-1.968	-3.598	-3.330	-6.193	-3.959
180	-4.424	-5.104	-4.353	-4.957	-5.428	-3.739	-4.497	-1.750	-1.792	-5.021	-3.879	-6.062	-4.946
195	-4.432	-5.141	-4.847	-5.056	-5.741	-3.737	-5.159	-1.673	-1.596	-5.218	-4.240	-5.739	-5.071
210	-5.031	-5.405	-4.371	-3.986	-4.857	-3.029	-3.697	-1.356	-1.329	-5.309	-3.074	-4.076	-3.132
225	-4.891	-5.684	-3.792	-2.566	-3.335	-1.732	-2.567	-1.586	-2.528	-2.971	-1.773	-2.518	-2.214
240	-4.677	-6.425	-4.365	-2.514	-1.313	-1.150	-2.785	-2.590	-4.048	-1.539	-1.300	-2.547	-2.308
255	-4.351	-6.614	-4.313	-2.268	-0.779	-0.807	-2.762	-3.403	-4.896	-0.939	-1.045	-2.356	-2.454
270	-3.734	-5.863	-4.038	-2.023	-1.322	-1.004	-2.752	-3.591	-4.743	-1.153	-1.086	-2.339	-2.391
285	-3.285	-3.788	-4.397	-2.003	-1.123	-1.849	-2.649	-3.188	-3.681	-1.366	-1.406	-2.392	-2.523
300	-2.826	-3.390	-4.461	-1.926	-1.202	-2.277	-2.412	-2.253	-2.579	-1.392	-1.982	-2.273	-2.593
315	-2.603	-3.683	-4.943	-2.310	-1.394	-3.898	-2.321	-1.722	-1.787	-1.433	-3.224	-2.107	-3.025
330	-2.526	-4.112	-5.258	-3.644	-1.737	-4.626	-2.927	-1.688	-1.676	-1.793	-4.201	-2.142	-3.337
345	-2.891	-3.553	-5.391	-4.472	-2.128	-4.891	-3.852	-1.860	-1.899	-2.237	-4.743	-2.921	-4.860

	Port 4 Negative Peak Pressure Coefficent												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**8A14**	**8A15**	**8B01**	**8B02**	**8C01**	**8C02**	**8C03**	**8C04**	**8C05**	**8C06**	**8C07**	**8C08**	**8C09**
0	-3.030	-3.029	-3.344	-2.961	-2.303	-2.378	-2.439	-2.295	-2.625	-2.372	-2.551	-2.257	-2.196
15	-2.741	-2.567	-3.231	-2.741	-2.368	-2.470	-2.573	-2.709	-3.849	-2.753	-4.222	-2.673	-3.210
30	-2.382	-2.504	-3.430	-2.482	-2.439	-2.469	-2.543	-2.706	-3.291	-3.503	-5.040	-3.250	-4.574
45	-2.248	-2.135	-3.572	-2.202	-2.958	-2.952	-3.326	-2.800	-2.963	-2.893	-3.508	-3.914	-4.211
60	-2.382	-2.574	-3.261	-2.312	-3.694	-3.338	-4.003	-3.181	-3.331	-3.045	-3.224	-2.790	-3.041
75	-2.150	-2.067	-2.380	-1.679	-4.877	-3.644	-3.825	-3.246	-3.186	-3.119	-3.012	-3.002	-2.733
90	-2.674	-2.380	-1.887	-2.219	-3.874	-2.973	-3.179	-2.608	-2.647	-2.486	-2.720	-2.303	-2.200
105	-3.753	-4.328	-3.273	-3.120	-3.107	-3.060	-3.740	-2.714	-2.866	-2.997	-2.993	-2.692	-2.676
120	-3.914	-4.261	-3.847	-3.166	-3.556	-3.017	-3.400	-2.355	-2.620	-2.144	-2.531	-1.825	-1.703
135	-5.018	-4.153	-3.017	-3.449	-2.784	-1.992	-2.270	-1.700	-1.603	-1.740	-1.702	-1.613	-1.541
150	-3.855	-3.104	-3.072	-3.901	-2.927	-1.934	-1.908	-2.290	-1.770	-1.946	-1.844	-2.102	-1.856
165	-3.908	-3.094	-4.368	-4.856	-4.075	-1.572	-2.153	-1.613	-1.525	-1.476	-1.836	-1.485	-1.283
180	-3.411	-3.002	-4.268	-4.766	-2.964	-1.529	-1.920	-1.488	-1.756	-1.431	-1.720	-1.580	-1.327
195	-2.499	-2.507	-3.858	-4.163	-2.638	-1.613	-1.703	-1.376	-1.585	-1.482	-1.751	-1.585	-1.445
210	-2.282	-2.308	-3.574	-3.303	-3.487	-1.743	-2.084	-1.651	-1.996	-1.575	-1.883	-1.605	-1.887
225	-2.323	-2.275	-2.653	-2.884	-3.225	-2.053	-2.360	-1.673	-1.928	-1.635	-1.872	-1.690	-1.952
240	-2.751	-2.826	-2.628	-2.864	-3.534	-1.950	-2.429	-1.645	-2.079	-1.588	-1.814	-1.535	-1.578
255	-2.799	-2.805	-4.020	-4.169	-3.094	-1.891	-2.041	-1.570	-1.792	-1.822	-1.757	-2.025	-1.757
270	-2.359	-2.628	-3.342	-4.288	-2.479	-1.701	-1.778	-1.612	-1.646	-1.816	-1.807	-2.392	-1.812
285	-1.990	-2.382	-1.413	-1.470	-1.749	-2.365	-1.590	-2.005	-1.772	-2.655	-2.068	-2.583	-1.701
300	-2.685	-3.182	-1.826	-1.762	-1.814	-1.943	-1.789	-2.830	-1.693	-2.627	-1.818	-2.366	-1.906
315	-2.947	-3.077	-2.993	-2.708	-1.806	-1.778	-1.879	-1.751	-1.757	-1.750	-1.647	-1.715	-1.406
330	-2.886	-2.883	-3.204	-2.896	-1.996	-1.869	-1.874	-1.778	-1.758	-1.857	-1.745	-1.773	-1.621
345	-2.858	-2.891	-3.561	-3.021	-1.888	-1.838	-1.881	-1.848	-1.853	-1.934	-1.894	-1.950	-1.787

	Port 5 Negative Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**8C10**	**8C11**	**8C12**	**8C13**	**8C14**	**8D01**	**8D02**	**8F01**	**8F02**	**7E01**	**7E02**	**7F01**	**7F02**
0	-2.231	-2.234	-2.209	-1.757	-2.217	-2.247	-2.278	-2.457	-3.849	-2.243	-2.196	-2.318	-3.249
15	-2.213	-2.356	-2.074	-1.694	-2.227	-2.199	-2.179	-2.490	-3.055	-2.107	-2.081	-2.396	-3.219
30	-3.248	-5.105	-2.574	-3.512	-2.423	-2.134	-2.097	-2.506	-2.760	-2.052	-2.040	-2.450	-2.854
45	-3.449	-5.069	-3.422	-3.650	-2.741	-2.086	-2.075	-2.676	-2.338	-1.996	-2.068	-2.587	-2.179
60	-2.574	-2.950	-2.515	-2.095	-2.671	-2.621	-2.200	-2.892	-2.416	-2.107	-2.108	-2.873	-2.215
75	-2.767	-2.369	-2.420	-1.862	-2.703	-2.983	-2.421	-2.801	-2.271	-2.361	-2.332	-2.605	-2.086
90	-2.141	-2.234	-2.274	-1.842	-2.895	-2.460	-1.841	-2.410	-1.884	-2.131	-2.052	-2.408	-1.775
105	-2.361	-2.534	-2.307	-2.097	-3.009	-2.073	-1.640	-1.916	-1.661	-1.745	-1.858	-1.933	-1.500
120	-1.562	-1.868	-1.571	-1.280	-2.008	-1.613	-1.497	-1.962	-1.509	-1.416	-1.439	-1.863	-1.444
135	-1.671	-1.724	-1.682	-1.243	-2.034	-2.000	-1.866	-2.530	-1.979	-1.801	-1.587	-2.354	-1.827
150	-1.793	-1.808	-1.822	-1.097	-2.123	-2.938	-1.654	-3.040	-2.876	-1.605	-1.499	-3.140	-2.768
165	-1.461	-1.277	-1.488	-0.656	-3.130	-2.987	-1.817	-3.899	-3.152	-2.254	-1.557	-3.988	-3.324
180	-1.603	-1.440	-1.817	-0.878	-2.661	-2.735	-1.440	-5.026	-3.847	-1.527	-1.636	-4.605	-4.094
195	-1.463	-1.537	-1.523	-0.995	-2.244	-2.085	-1.442	-5.571	-3.773	-1.245	-1.337	-5.019	-3.906
210	-1.604	-1.724	-1.482	-1.351	-2.177	-1.595	-0.981	-4.848	-2.768	-0.944	-1.114	-4.587	-2.530
225	-1.286	-1.673	-1.917	-1.221	-2.124	-1.098	-0.843	-3.686	-1.801	-0.796	-1.327	-3.588	-1.624
240	-1.933	-1.799	-2.337	-1.627	-3.195	-1.306	-0.935	-1.889	-1.193	-0.878	-3.131	-1.682	-1.244
255	-2.119	-2.024	-2.518	-1.815	-3.163	-2.064	-1.627	-0.921	-0.885	-1.897	-4.646	-0.899	-0.905
270	-2.369	-2.192	-2.539	-1.873	-2.647	-2.520	-1.855	-1.029	-1.201	-1.947	-4.455	-0.990	-1.054
285	-2.799	-2.073	-2.850	-1.806	-2.574	-2.948	-2.233	-0.997	-1.937	-2.407	-3.360	-1.234	-2.092
300	-1.796	-1.634	-1.993	-1.384	-2.468	-2.517	-2.125	-1.237	-2.763	-2.359	-2.554	-1.229	-2.793
315	-1.711	-1.528	-1.714	-1.205	-2.151	-2.147	-1.780	-1.296	-3.904	-1.823	-1.871	-1.352	-3.502
330	-1.656	-1.646	-1.656	-1.262	-1.877	-1.789	-1.740	-1.648	-4.230	-1.747	-1.708	-1.579	-4.236
345	-2.138	-1.914	-1.858	-1.465	-2.016	-2.061	-2.017	-2.022	-4.106	-1.971	-1.959	-1.999	-3.920

	Port 6 Negative Peak Pressure Coefficients												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**6C01**	**6C02**	**6C03**	**6C04**	**6C05**	**7C01**	**7C02**	**7C03**	**7C04**	**7C06**	**7C07**	**7C08**	**7D01**
0	-2.235	-2.279	-2.020	-1.659	-2.120	-2.175	-2.174	-2.156	-2.035	-2.065	-2.090	-2.161	-2.206
15	-2.192	-2.225	-2.373	-1.590	-2.104	-2.185	-2.246	-2.377	-2.397	-2.047	-2.017	-2.103	-2.039
30	-2.269	-2.210	-2.474	-1.772	-1.963	-2.298	-2.200	-2.300	-2.503	-2.346	-2.220	-2.024	-2.008
45	-2.433	-2.423	-2.369	-2.026	-2.237	-2.506	-2.438	-2.362	-2.393	-2.600	-2.450	-2.358	-2.012
60	-2.817	-2.880	-2.717	-2.047	-2.973	-3.049	-2.819	-2.768	-2.871	-2.629	-2.571	-2.947	-2.640
75	-3.291	-3.356	-3.238	-2.227	-3.443	-3.835	-3.124	-3.237	-3.393	-3.034	-2.703	-3.152	-3.034
90	-2.541	-2.426	-2.339	-1.886	-3.059	-3.235	-2.562	-2.277	-2.430	-2.143	-2.326	-2.880	-2.665
105	-1.803	-2.015	-2.040	-1.344	-2.787	-1.981	-2.101	-2.168	-2.022	-2.088	-2.068	-2.755	-2.305
120	-2.123	-1.846	-1.430	-0.956	-2.126	-2.509	-2.090	-1.789	-1.587	-1.303	-1.414	-2.162	-1.666
135	-2.397	-1.414	-1.027	-0.850	-2.148	-2.139	-1.408	-1.229	-1.319	-1.382	-1.411	-2.202	-1.888
150	-2.916	-1.432	-1.176	-0.924	-2.106	-2.981	-1.696	-1.711	-1.385	-1.468	-1.623	-2.227	-2.751
165	-3.717	-1.577	-1.069	-0.438	-2.230	-3.256	-1.573	-1.543	-0.948	-1.142	-0.985	-2.892	-3.199
180	-2.966	-1.202	-0.878	-0.530	-2.264	-2.744	-1.050	-1.141	-1.180	-1.043	-1.258	-2.660	-2.325
195	-3.145	-1.453	-1.006	-0.712	-1.988	-3.005	-1.202	-1.034	-1.231	-1.138	-1.054	-2.321	-1.753
210	-3.270	-1.673	-1.031	-0.839	-1.814	-3.450	-1.395	-1.230	-1.353	-1.185	-1.329	-1.853	-1.450
225	-3.261	-1.820	-1.138	-0.954	-2.001	-3.324	-1.498	-1.528	-1.237	-1.075	-1.551	-1.997	-0.897
240	-3.280	-1.560	-1.176	-1.316	-2.438	-3.164	-1.597	-1.142	-1.235	-1.519	-1.875	-3.013	-1.030
255	-3.164	-1.551	-1.344	-1.567	-2.629	-3.226	-1.527	-1.467	-1.466	-1.855	-2.209	-3.000	-1.786
270	-2.346	-1.433	-1.558	-1.552	-1.909	-2.498	-1.399	-1.534	-1.577	-1.888	-2.114	-2.524	-2.368
285	-1.456	-1.372	-1.488	-1.525	-2.373	-1.533	-1.536	-1.594	-1.589	-1.930	-2.088	-2.442	-2.808
300	-1.559	-1.451	-1.420	-1.210	-2.048	-1.554	-1.495	-1.527	-1.646	-1.637	-1.693	-2.321	-2.429
315	-1.656	-1.585	-1.492	-1.132	-2.012	-1.668	-1.551	-1.495	-1.566	-1.560	-1.597	-2.098	-2.106
330	-1.749	-1.718	-1.566	-1.178	-1.671	-1.762	-1.712	-1.677	-1.573	-1.543	-1.559	-1.692	-1.605
345	-1.826	-1.710	-1.625	-1.397	-1.829	-1.873	-1.742	-1.702	-1.657	-1.756	-1.785	-1.881	-1.840

	Port 7 Negative Peak Pressure Coefficients												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**6A01**	**6A02**	**6A03**	**6A04**	**6A05**	**7A01**	**7A02**	**7A03**	**7A04**	**7A05**	**7A06**	**7C05**	**00J01**
0	-1.145	-0.682	-0.606	-0.623	-3.273	-0.906	-0.803	-0.695	-0.842	-0.959	-3.044	-2.030	-3.831
15	-1.458	-0.787	-0.771	-0.789	-2.739	-1.012	-1.037	-0.938	-1.134	-0.991	-2.518	-2.062	-4.651
30	-1.569	-0.794	-0.655	-0.773	-3.031	-0.891	-0.897	-0.975	-1.048	-1.673	-2.405	-2.869	-5.168
45	-1.529	-0.851	-0.848	-0.809	-1.523	-0.951	-0.987	-1.509	-1.106	-1.852	-1.821	-2.533	-5.338
60	-1.218	-0.813	-0.760	-0.922	-1.631	-0.852	-0.987	-1.063	-1.111	-1.954	-1.760	-2.674	-5.021
75	-1.258	-0.808	-0.795	-1.145	-1.384	-0.814	-0.903	-0.890	-1.183	-1.974	-1.797	-3.276	-4.717
90	-1.185	-0.720	-0.750	-0.979	-1.715	-0.819	-0.815	-0.792	-0.853	-1.147	-2.104	-2.417	-4.508
105	-1.189	-1.129	-0.902	-1.061	-1.769	-1.904	-1.307	-1.195	-1.308	-1.494	-2.527	-1.902	-4.906
120	-1.742	-1.665	-1.168	-1.367	-1.877	-2.974	-1.799	-1.424	-1.570	-1.833	-2.808	-1.555	-4.481
135	-1.922	-1.978	-1.585	-1.720	-4.534	-2.535	-1.721	-1.718	-1.772	-1.893	-4.811	-1.283	-5.125
150	-1.865	-1.803	-1.710	-1.857	-4.287	-2.150	-1.794	-2.049	-1.945	-1.877	-5.044	-1.407	-4.929
165	-1.886	-1.806	-1.815	-1.947	-2.518	-1.943	-1.806	-1.984	-2.039	-2.045	-2.990	-0.830	-4.982
180	-1.987	-1.951	-1.770	-1.927	-2.324	-2.088	-1.935	-1.941	-2.064	-2.072	-2.692	-1.106	-5.584
195	-2.040	-2.004	-1.956	-2.012	-2.315	-2.027	-2.007	-2.043	-2.116	-2.083	-2.359	-1.175	-5.623
210	-1.925	-1.906	-1.871	-1.968	-2.229	-1.910	-1.864	-1.966	-2.033	-2.053	-2.314	-1.036	-5.078
225	-1.835	-1.820	-1.778	-1.821	-2.025	-1.831	-1.778	-1.835	-1.917	-1.884	-1.991	-1.081	-3.982
240	-1.875	-2.009	-1.944	-2.060	-2.227	-1.950	-1.865	-2.046	-2.235	-2.198	-2.219	-1.396	-3.612
255	-1.808	-2.047	-1.927	-2.059	-2.328	-2.002	-1.902	-1.990	-2.166	-2.229	-2.523	-1.548	-3.470
270	-1.540	-1.762	-1.582	-1.664	-2.555	-1.750	-1.598	-1.589	-1.662	-1.690	-2.215	-1.676	-2.608
285	-1.518	-1.934	-1.700	-1.649	-1.884	-1.861	-1.676	-1.903	-1.815	-1.685	-1.989	-1.786	-1.791
300	-1.595	-1.990	-1.690	-1.380	-2.533	-1.881	-1.636	-1.566	-1.470	-1.598	-2.708	-1.579	-1.611
315	-1.429	-1.892	-1.212	-1.187	-3.583	-1.586	-1.343	-1.175	-1.186	-1.457	-3.290	-1.508	-1.889
330	-1.195	-1.387	-0.923	-0.769	-4.105	-1.157	-1.137	-1.162	-1.130	-1.155	-3.673	-1.502	-2.183
345	-0.974	-0.836	-0.801	-0.734	-3.709	-1.087	-0.849	-0.954	-0.929	-1.193	-3.096	-1.887	-3.295

	Port 8 Negative Peak Pressure Coefficients												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**1A01**	**1A02**	**1A03**	**1A04**	**2A01**	**2C01**	**2C02**	**2C03**	**2C04**	**2C05**	**3A01**	**3A02**	**3A03**
0	-0.460	-0.542	-0.483	-2.756	-3.111	-2.039	-2.034	-1.918	-1.888	-1.919	-0.605	-0.506	-3.420
15	-0.618	-0.506	-0.589	-2.233	-2.447	-2.136	-2.117	-2.024	-1.888	-1.905	-0.879	-0.563	-2.757
30	-0.474	-0.267	-0.350	-1.802	-2.126	-2.377	-2.345	-2.326	-2.164	-2.022	-0.424	-0.384	-2.499
45	-0.518	-0.364	-0.405	-1.878	-1.435	-2.377	-2.361	-2.390	-2.257	-2.033	-0.474	-0.459	-1.503
60	-0.633	-0.555	-0.720	-2.539	-1.485	-2.582	-2.469	-2.297	-1.994	-1.738	-0.631	-0.660	-1.424
75	-0.618	-0.621	-0.606	-2.494	-1.805	-2.511	-2.395	-1.580	-1.525	-1.503	-0.616	-0.675	-1.405
90	-0.511	-0.557	-0.629	-1.750	-1.774	-1.810	-1.598	-1.439	-1.345	-1.250	-0.548	-0.689	-1.560
105	-0.706	-0.759	-0.880	-1.514	-1.595	-1.445	-1.463	-1.433	-1.220	-1.108	-0.807	-1.041	-1.407
120	-0.895	-0.970	-1.093	-1.456	-1.372	-1.373	-1.278	-1.065	-0.906	-0.893	-0.982	-1.105	-1.884
135	-1.406	-1.431	-1.516	-2.614	-2.887	-1.370	-1.089	-0.801	-0.938	-1.135	-1.500	-1.551	-2.475
150	-1.664	-1.780	-2.051	-2.223	-2.889	-1.415	-0.960	-0.888	-0.961	-1.042	-1.751	-2.169	-3.133
165	-1.686	-1.745	-1.907	-2.053	-2.119	-1.410	-0.853	-0.713	-0.684	-0.830	-1.765	-1.928	-2.192
180	-1.884	-1.972	-2.042	-2.191	-2.268	-1.436	-0.719	-0.572	-0.642	-0.913	-1.943	-1.946	-2.351
195	-1.879	-1.884	-1.974	-2.234	-2.341	-1.380	-0.917	-0.664	-0.604	-0.834	-1.897	-1.915	-2.321
210	-1.872	-1.942	-1.988	-2.088	-2.116	-1.562	-1.089	-0.844	-0.693	-1.002	-1.893	-2.006	-2.142
225	-1.738	-1.788	-1.849	-1.948	-1.985	-1.528	-1.100	-0.869	-0.775	-1.174	-1.772	-1.834	-1.987
240	-1.713	-1.789	-1.975	-2.022	-2.275	-1.727	-1.226	-0.981	-0.995	-1.641	-1.787	-1.834	-2.245
255	-1.479	-1.705	-1.822	-1.947	-2.614	-1.725	-1.227	-1.047	-1.267	-1.910	-1.705	-1.902	-2.513
270	-1.267	-1.521	-1.805	-1.823	-3.001	-1.465	-1.181	-1.179	-1.370	-1.869	-1.471	-1.682	-2.774
285	-1.253	-1.415	-1.278	-1.303	-1.676	-1.135	-1.188	-1.277	-1.487	-1.695	-1.476	-1.461	-2.320
300	-0.938	-1.206	-0.939	-1.632	-2.071	-1.460	-1.353	-1.312	-1.466	-1.789	-1.201	-1.238	-2.633
315	-0.826	-0.993	-0.760	-2.262	-2.358	-1.583	-1.553	-1.423	-1.486	-1.603	-1.429	-1.047	-2.793
330	-0.600	-0.813	-0.765	-2.642	-2.667	-1.881	-1.810	-1.572	-1.631	-1.713	-1.302	-0.906	-3.165
345	-0.600	-0.537	-0.496	-2.215	-2.761	-1.890	-1.857	-1.719	-1.766	-1.804	-0.721	-0.656	-2.974

	Port 9 Negative Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**3B01**	**3B02**	**3C01**	**3C02**	**4A01**	**4C01**	**4C02**	**4C04**	**4C05**	**5A01**	**5A02**	**5A03**	**5B01**
0	-3.368	-2.463	-2.089	-1.991	-3.386	-2.059	-2.137	-1.881	-1.992	-0.512	-0.601	-3.500	-3.420
15	-3.307	-2.316	-2.390	-1.944	-3.238	-2.312	-2.267	-2.071	-2.038	-0.574	-0.663	-3.386	-3.523
30	-3.339	-2.300	-2.493	-2.071	-2.260	-2.396	-2.340	-2.220	-2.128	-0.498	-0.657	-2.708	-3.461
45	-3.277	-2.036	-2.673	-2.075	-1.984	-2.593	-2.552	-2.414	-2.201	-0.664	-0.848	-1.638	-3.748
60	-2.468	-1.669	-3.317	-2.178	-1.716	-3.181	-3.149	-2.459	-2.650	-0.677	-0.808	-1.387	-2.797
75	-1.864	-1.400	-3.538	-2.185	-1.570	-3.173	-3.360	-2.016	-3.321	-0.740	-0.937	-1.693	-2.224
90	-1.807	-1.423	-2.731	-1.671	-1.438	-2.549	-2.212	-1.592	-2.672	-0.655	-0.873	-1.789	-2.317
105	-2.234	-1.990	-1.860	-1.415	-1.820	-1.859	-1.666	-1.473	-2.342	-0.931	-1.228	-2.350	-3.280
120	-2.080	-3.383	-1.839	-1.157	-2.105	-2.061	-1.752	-1.050	-1.780	-1.313	-1.342	-2.353	-2.434
135	-2.409	-3.289	-2.786	-1.292	-4.560	-2.151	-1.016	-0.841	-1.893	-1.482	-1.786	-5.144	-2.592
150	-2.797	-3.335	-2.771	-1.487	-3.569	-2.867	-1.383	-0.966	-1.791	-1.802	-1.934	-4.908	-2.721
165	-3.398	-3.823	-3.051	-1.250	-2.288	-3.224	-1.296	-0.627	-1.538	-1.843	-1.982	-2.624	-3.413
180	-5.292	-4.471	-2.996	-1.457	-2.213	-3.175	-1.143	-0.676	-1.732	-1.902	-2.006	-2.216	-3.335
195	-3.515	-3.526	-3.347	-1.718	-2.307	-3.307	-1.402	-0.656	-1.754	-1.878	-2.039	-2.308	-3.290
210	-3.149	-3.039	-2.770	-1.703	-2.162	-3.385	-1.371	-0.842	-1.884	-1.909	-1.924	-2.134	-2.740
225	-2.497	-2.716	-2.837	-2.528	-2.089	-2.998	-1.472	-0.969	-3.067	-1.811	-1.879	-2.096	-2.475
240	-2.470	-2.671	-2.589	-3.278	-2.494	-3.101	-1.528	-1.446	-3.398	-1.966	-1.919	-2.443	-2.513
255	-2.535	-3.032	-2.861	-4.021	-2.887	-3.166	-1.671	-1.806	-4.064	-1.665	-1.908	-2.939	-2.565
270	-2.102	-2.863	-2.303	-3.258	-3.530	-2.597	-1.490	-1.828	-4.026	-1.512	-1.653	-3.703	-2.420
285	-1.370	-1.704	-1.357	-2.486	-1.902	-1.462	-1.238	-1.902	-2.832	-1.633	-1.546	-2.161	-1.600
300	-1.761	-1.641	-1.973	-2.162	-2.373	-1.928	-1.552	-1.579	-2.306	-2.191	-1.435	-2.929	-1.806
315	-2.360	-1.916	-1.845	-1.804	-3.484	-1.712	-1.628	-1.370	-1.890	-1.151	-1.235	-3.434	-2.625
330	-2.669	-2.089	-1.791	-1.612	-3.688	-1.736	-1.663	-1.513	-1.677	-1.108	-1.069	-3.670	-2.930
345	-3.101	-2.245	-2.078	-1.793	-3.108	-2.043	-1.936	-1.697	-1.825	-0.790	-0.956	-3.565	-3.435

	Port 10 Negative Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**5B02**	**5C01**	**5C02**	**5C03**	**5C04**	**5D01**	**5F01**	**5F02**	**6D01**	**6D02**	**6F01**	**6F02**	**7B01**
0	-2.787	-2.200	-2.212	-1.901	-2.101	-2.114	-2.288	-2.304	-2.135	-2.133	-2.312	-3.306	-3.857
15	-2.704	-2.329	-2.334	-2.307	-2.158	-2.197	-2.294	-2.400	-2.234	-2.145	-2.283	-2.748	-3.473
30	-2.399	-2.428	-2.490	-2.557	-2.125	-2.097	-2.403	-2.517	-2.100	-2.059	-2.415	-2.663	-3.173
45	-2.158	-2.624	-2.627	-2.648	-2.467	-2.059	-2.320	-2.394	-2.075	-1.926	-2.389	-2.350	-2.399
60	-1.872	-2.906	-2.915	-2.518	-2.630	-2.595	-2.261	-2.274	-2.686	-1.820	-2.601	-2.143	-2.119
75	-1.512	-2.970	-3.036	-2.913	-3.261	-3.511	-2.722	-2.183	-3.286	-2.264	-3.155	-2.081	-1.641
90	-1.622	-2.255	-2.142	-1.987	-2.996	-3.017	-2.195	-2.088	-3.020	-2.124	-2.551	-1.876	-1.414
105	-2.805	-1.673	-1.788	-1.640	-2.730	-2.485	-1.711	-1.638	-2.730	-1.899	-2.126	-1.689	-2.122
120	-2.290	-2.084	-1.576	-1.400	-2.013	-1.684	-1.950	-1.469	-1.882	-1.322	-2.078	-1.568	-2.193
135	-2.664	-2.757	-1.164	-1.026	-2.140	-2.460	-1.996	-1.655	-2.333	-1.538	-2.531	-1.714	-2.186
150	-3.481	-3.342	-1.149	-0.933	-1.949	-1.925	-2.270	-1.854	-2.301	-1.291	-3.013	-1.996	-2.701
165	-3.620	-3.266	-0.973	-0.718	-1.737	-2.532	-2.836	-2.177	-4.239	-1.158	-3.577	-2.383	-3.294
180	-4.283	-3.225	-1.022	-0.659	-1.994	-1.866	-3.258	-2.363	-2.602	-1.163	-4.628	-2.794	-2.933
195	-3.737	-3.367	-1.004	-0.836	-1.528	-1.721	-2.895	-2.423	-1.520	-0.958	-4.374	-2.774	-2.637
210	-2.902	-3.365	-1.282	-1.060	-1.949	-1.125	-2.208	-1.917	-1.162	-0.927	-3.839	-1.974	-2.325
225	-2.707	-3.045	-1.272	-1.033	-2.561	-1.029	-1.852	-1.513	-0.868	-0.837	-3.305	-1.601	-2.422
240	-2.495	-3.280	-1.356	-1.242	-3.118	-0.986	-1.352	-1.385	-1.090	-0.781	-1.872	-1.450	-2.556
255	-2.840	-3.101	-1.507	-1.678	-3.509	-2.146	-1.182	-0.933	-1.974	-1.708	-1.156	-1.170	-2.543
270	-2.902	-2.408	-1.373	-1.690	-2.930	-2.581	-1.350	-1.452	-2.519	-2.088	-1.456	-1.669	-2.251
285	-1.512	-1.527	-1.398	-1.582	-2.430	-2.647	-1.390	-1.801	-2.782	-2.243	-1.396	-2.123	-1.490
300	-1.606	-1.903	-1.366	-1.484	-2.115	-2.751	-1.583	-2.672	-2.738	-2.288	-1.475	-3.185	-1.873
315	-2.119	-1.685	-1.548	-1.382	-1.921	-1.959	-1.409	-2.625	-2.032	-1.761	-1.381	-3.792	-2.543
330	-2.171	-1.820	-1.621	-1.633	-1.814	-1.775	-1.692	-2.839	-1.780	-1.744	-1.668	-4.101	-3.131
345	-2.542	-1.796	-1.695	-1.704	-1.891	-1.821	-1.939	-2.262	-1.849	-1.818	-1.892	-2.920	-3.772

	Port 11 Negative Peak Pressure Coefficients												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**0C01**	**0B02**	**0B01**	**0A04**	**0RR1**	**0RR2**	**0RR3**	**0RR4**	**0RR5**	**0RR6**	**0RR7**	**0RR8**	**0D01**
0	-2.447	-3.328	-3.768	-5.810	-5.215	-5.954	-4.399	-4.043	-3.803	-3.877	-3.415	-2.938	-3.159
15	-2.545	-3.342	-4.686	-6.751	-5.882	-7.036	-3.873	-4.558	-3.402	-3.716	-2.628	-3.140	-3.510
30	-3.109	-4.195	-5.670	-6.593	-5.806	-7.631	-4.239	-5.657	-3.706	-4.750	-3.533	-4.225	-3.755
45	-3.976	-4.510	-5.736	-5.948	-5.495	-8.343	-4.715	-7.028	-4.226	-5.114	-3.669	-4.667	-2.843
60	-4.266	-4.758	-5.000	-6.196	-5.306	-7.944	-4.472	-8.703	-4.554	-5.529	-3.760	-5.315	-2.513
75	-3.564	-4.044	-4.366	-4.749	-3.995	-6.460	-4.238	-7.855	-4.448	-5.067	-2.889	-5.065	-1.905
90	-2.183	-2.924	-3.071	-3.125	-2.764	-4.538	-2.952	-4.757	-2.184	-3.331	-1.918	-3.150	-1.589
105	-1.997	-1.763	-1.514	-2.029	-1.971	-2.658	-1.758	-2.043	-1.812	-2.151	-1.963	-2.540	-1.139
120	-2.739	-2.430	-1.778	-2.640	-2.508	-2.972	-2.224	-2.577	-2.535	-2.369	-2.402	-2.836	-2.320
135	-4.269	-2.821	-1.609	-2.350	-2.149	-2.743	-1.970	-2.646	-2.110	-2.524	-3.812	-3.686	-3.289
150	-5.156	-2.645	-1.631	-1.908	-1.880	-2.694	-2.014	-2.634	-2.356	-2.626	-5.058	-4.532	-5.730
165	-6.437	-3.675	-2.237	-2.445	-2.688	-2.895	-3.206	-3.021	-4.311	-3.624	-5.758	-5.719	-6.326
180	-5.738	-3.785	-2.456	-2.929	-3.137	-3.144	-3.681	-3.522	-4.249	-3.828	-5.611	-5.542	-6.419
195	-5.358	-3.762	-2.683	-3.012	-3.244	-3.352	-3.703	-3.557	-3.867	-3.975	-5.433	-5.730	-5.770
210	-5.888	-4.145	-2.590	-2.971	-3.078	-3.227	-3.772	-3.617	-3.631	-3.778	-5.031	-5.829	-5.176
225	-4.835	-3.047	-2.064	-2.405	-2.513	-2.477	-2.735	-2.544	-3.123	-2.948	-4.483	-4.552	-4.246
240	-4.806	-2.618	-1.734	-1.881	-2.124	-2.006	-2.227	-2.190	-2.524	-2.529	-3.593	-3.569	-5.284
255	-3.646	-2.072	-1.442	-1.973	-1.810	-1.948	-1.939	-1.852	-1.966	-1.975	-2.540	-2.624	-4.589
270	-2.687	-1.636	-1.600	-2.187	-2.333	-2.123	-2.088	-2.005	-1.862	-1.810	-2.014	-2.058	-4.166
285	-2.082	-1.601	-1.495	-2.885	-2.247	-2.155	-2.003	-2.186	-1.690	-1.709	-1.798	-1.809	-3.482
300	-2.223	-1.841	-1.866	-3.835	-2.926	-3.090	-2.172	-2.094	-1.928	-1.864	-2.156	-2.257	-3.164
315	-1.865	-2.360	-2.374	-5.502	-4.531	-4.620	-3.116	-2.881	-2.414	-2.508	-1.965	-2.123	-1.906
330	-2.355	-3.087	-3.032	-5.434	-4.705	-4.497	-3.519	-3.433	-3.276	-3.522	-2.383	-2.565	-1.820
345	-2.827	-3.078	-3.421	-5.778	-5.082	-5.816	-4.313	-3.951	-3.409	-3.981	-3.016	-3.576	-2.110

	Port 12 Negative Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**0RL1**	**0RL2**	**0RL3**	**0RL4**	**0RL5**	**0RL6**	**0RL7**	**0RL8**	**0RL13**	**0RL12**	**0RL11**	**0RL10**	**0RL9**
0	-4.596	-4.350	-3.755	-3.745	-3.170	-3.332	-2.718	-3.300	-3.511	-3.089	-2.676	-4.804	-6.292
15	-4.571	-4.421	-3.922	-3.777	-3.515	-3.486	-3.061	-3.495	-3.253	-3.622	-3.421	-5.415	-7.830
30	-4.981	-4.605	-3.908	-3.969	-3.312	-3.566	-3.124	-3.258	-3.521	-3.300	-3.429	-6.189	-8.050
45	-4.720	-4.603	-3.688	-3.636	-3.074	-3.310	-2.741	-2.883	-2.866	-3.108	-3.701	-5.041	-7.432
60	-4.378	-3.908	-3.168	-3.411	-2.770	-3.078	-2.563	-2.745	-2.619	-2.694	-3.843	-5.090	-7.349
75	-3.010	-2.706	-2.485	-2.454	-2.525	-2.491	-2.231	-2.263	-2.358	-2.510	-5.306	-3.643	-5.823
90	-1.645	-1.564	-1.308	-1.402	-1.511	-1.385	-1.311	-1.277	-1.529	-1.986	-6.626	-2.329	-4.532
105	-1.199	-1.227	-1.020	-1.060	-1.230	-1.237	-1.304	-1.348	-1.310	-1.626	-6.048	-1.372	-1.895
120	-1.136	-1.219	-1.394	-1.317	-1.805	-1.865	-2.295	-2.502	-2.223	-1.511	-3.898	-2.164	-2.734
135	-1.563	-1.693	-2.504	-1.859	-2.604	-2.521	-2.695	-3.431	-3.234	-1.783	-3.087	-2.725	-3.341
150	-2.961	-2.501	-4.452	-2.929	-3.805	-3.734	-4.698	-4.992	-4.861	-2.356	-4.131	-3.670	-3.925
165	-4.634	-3.848	-4.538	-3.881	-4.400	-5.272	-5.538	-5.693	-5.967	-2.979	-3.962	-4.947	-4.401
180	-6.049	-5.592	-5.205	-3.495	-4.285	-4.762	-5.235	-5.452	-5.452	-3.395	-4.006	-6.181	-4.850
195	-6.225	-6.388	-5.066	-3.399	-4.183	-5.063	-5.398	-5.956	-5.600	-3.227	-4.426	-6.048	-4.617
210	-5.534	-5.769	-4.856	-4.096	-3.461	-4.455	-5.163	-5.770	-5.019	-3.151	-3.750	-3.045	-2.562
225	-3.189	-4.837	-3.634	-3.123	-2.983	-3.183	-3.989	-4.517	-4.035	-3.181	-4.558	-2.480	-2.383
240	-2.625	-2.673	-3.374	-3.307	-3.320	-3.047	-3.234	-3.580	-3.782	-3.481	-4.858	-2.571	-2.573
255	-2.310	-2.303	-2.340	-2.280	-2.754	-2.803	-2.764	-2.688	-3.947	-2.983	-5.049	-2.871	-2.316
270	-1.995	-2.112	-2.237	-2.115	-2.483	-2.221	-2.344	-2.427	-3.466	-2.553	-5.007	-2.932	-2.420
285	-2.074	-2.106	-2.367	-2.401	-2.497	-2.338	-2.340	-2.473	-3.045	-2.528	-4.106	-3.043	-2.754
300	-2.202	-2.459	-2.164	-2.353	-2.177	-2.119	-2.184	-2.109	-2.423	-2.090	-2.559	-3.190	-2.521
315	-2.785	-3.256	-2.019	-2.228	-1.878	-2.072	-1.729	-1.776	-1.835	-1.967	-2.296	-3.029	-2.339
330	-3.433	-4.212	-2.681	-2.849	-2.257	-2.521	-1.844	-1.853	-1.891	-2.058	-2.046	-3.373	-3.284
345	-4.222	-5.106	-3.200	-3.285	-2.827	-2.986	-2.398	-2.505	-2.385	-2.525	-2.312	-4.318	-5.855

	Port 1 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**8A01**	**8A02**	**8A03**	**8A04**	**8A05**	**8A06**	**8A07**	**8A08**	**8A09**	**8A10**	**8A11**	**8A12**	**8A13**
0	2.341	4.128	3.962	4.307	4.280	4.068	4.204	4.330	4.030	4.179	4.456	3.847	4.566
15	1.178	3.896	3.230	3.704	3.473	3.873	3.795	4.100	3.469	4.267	4.077	4.455	4.950
30	0.911	3.382	2.996	3.186	3.234	3.550	3.161	3.907	2.933	4.116	3.407	4.023	4.105
45	1.216	3.188	3.106	3.012	2.987	3.627	2.724	3.506	2.902	4.320	2.927	3.669	3.446
60	1.429	2.775	2.565	2.953	2.607	3.235	2.237	3.259	2.421	3.682	2.393	3.190	2.817
75	1.527	2.470	2.225	2.169	2.092	2.687	2.159	2.870	1.825	3.019	1.949	2.375	1.993
90	1.989	2.349	2.208	2.149	2.026	2.259	1.927	2.193	1.695	2.567	1.760	2.208	1.622
105	1.560	2.053	1.850	1.630	1.605	1.879	1.750	1.793	1.605	1.802	1.486	1.572	1.508
120	1.075	1.403	1.337	1.378	1.282	1.433	1.389	1.438	1.306	1.323	1.186	1.220	1.290
135	0.559	0.647	0.556	0.573	0.527	0.595	0.624	0.479	0.471	0.499	0.431	0.492	0.527
150	0.297	0.371	0.331	0.303	0.282	0.363	0.389	0.194	0.191	0.165	0.174	0.183	0.247
165	0.111	0.167	0.156	0.152	0.160	0.109	0.126	0.048	0.052	0.030	0.048	0.069	0.170
180	0.006	0.231	0.240	0.256	0.299	0.186	0.242	0.089	0.135	0.093	0.077	0.026	0.170
195	0.062	0.185	0.142	0.233	0.304	0.333	0.396	0.186	0.258	0.096	0.111	0.015	0.205
210	0.011	0.156	0.135	0.105	0.142	0.173	0.248	0.093	0.130	0.049	0.136	-0.023	0.132
225	0.120	0.120	0.062	0.153	0.176	0.153	0.233	0.209	0.215	0.209	0.201	0.175	0.352
240	0.193	0.079	0.069	0.122	0.121	0.172	0.248	0.228	0.225	0.285	0.354	0.301	0.441
255	0.404	0.121	0.128	0.168	0.216	0.233	0.277	0.324	0.332	0.423	0.389	0.364	0.610
270	0.618	0.349	0.337	0.393	0.441	0.516	0.524	0.642	0.584	0.870	0.881	0.910	1.144
285	0.775	0.351	0.358	0.803	1.089	1.156	1.378	1.420	1.612	1.671	1.994	1.772	2.213
300	0.923	1.033	0.855	2.342	2.547	2.829	3.232	3.201	3.256	3.092	3.813	2.663	3.361
315	1.349	3.279	2.882	3.839	3.952	3.898	4.458	3.742	4.106	3.595	4.509	3.397	4.477
330	2.055	3.425	3.507	3.927	4.273	3.626	4.076	3.812	4.000	3.942	4.460	3.579	4.244
345	2.540	3.605	3.309	3.575	3.671	3.482	3.840	4.251	4.296	3.905	4.183	3.962	4.853

	Tap 2 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**0A03**	**0C02**	**0A02**	**0C03**	**0RM1**	**0RM2**	**0RM3**	**0RM4**	**0RM5**	**0RM6**	**0RM7**	**0RM8**	**0RM9**
0	-0.139	0.699	0.027	0.526	0.086	0.217	0.267	0.216	0.559	0.546	0.604	0.904	0.552
15	-0.473	0.856	0.115	0.627	0.367	0.171	0.267	0.250	0.423	0.346	0.537	0.335	0.352
30	-0.354	0.951	0.068	0.837	0.141	0.109	0.295	0.151	0.322	0.358	0.655	0.406	0.292
45	-0.328	1.016	0.064	0.830	0.266	0.017	0.247	0.284	0.416	0.556	0.565	0.449	0.503
60	0.181	1.022	0.213	0.735	0.316	0.274	0.477	0.484	0.607	0.756	0.664	0.546	0.531
75	0.985	1.296	1.126	1.189	1.155	1.178	1.132	1.096	1.004	1.034	0.895	0.834	1.052
90	1.554	1.334	1.789	1.359	1.518	1.552	1.394	1.338	1.284	1.282	1.194	1.198	1.307
105	1.564	1.595	1.630	1.520	1.542	1.419	1.450	1.401	1.430	1.381	1.345	1.387	1.381
120	1.481	1.616	1.621	1.679	1.344	1.346	1.283	1.334	1.246	1.404	1.347	1.400	1.300
135	1.410	0.966	1.524	0.712	1.025	0.953	0.877	0.943	0.880	0.982	1.030	0.995	0.935
150	1.383	0.599	1.456	0.624	0.771	0.780	0.897	0.874	1.034	0.897	0.943	0.854	0.972
165	0.969	0.292	1.333	0.102	0.664	0.682	0.611	0.595	0.859	0.644	0.917	0.528	0.855
180	0.716	-0.334	1.437	-0.287	0.590	0.712	0.386	0.486	0.341	0.280	0.218	0.046	0.455
195	0.651	-0.520	1.609	-0.679	0.407	0.442	0.261	0.177	0.062	0.218	-0.150	-0.086	0.187
210	0.772	-0.581	1.468	-0.213	0.668	0.554	0.470	0.433	0.250	0.113	0.015	0.253	0.494
225	0.804	-0.293	1.007	-0.171	0.588	0.558	0.625	0.475	0.295	0.415	0.115	0.567	0.476
240	0.673	0.222	0.683	0.436	0.579	0.571	0.499	0.475	0.394	0.395	0.399	0.465	0.469
255	0.762	0.643	0.730	0.822	0.926	0.801	0.709	0.598	0.650	0.615	0.731	0.593	0.710
270	0.960	1.003	0.709	0.995	0.929	1.127	0.942	1.086	0.832	0.979	0.985	0.920	0.976
285	1.305	1.355	0.388	1.005	0.923	0.958	0.802	0.989	1.051	1.294	1.447	1.207	0.918
300	1.208	1.227	0.657	1.084	0.842	0.971	0.742	0.800	0.816	0.954	1.202	1.048	0.724
315	0.614	1.291	1.008	1.040	0.834	1.120	1.010	0.995	0.883	0.904	1.017	0.949	0.931
330	0.154	1.061	0.144	1.153	0.361	0.583	0.651	0.713	0.679	0.715	0.747	0.610	0.649
345	0.016	0.801	-0.015	0.856	0.225	0.197	0.351	0.417	0.665	0.632	0.622	0.689	0.505

	Port 3 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**00K01**	**00L01**	**00L02**	**9J01**	**9L01**	**9L02**	**10J01**	**10K01**	**10K02**	**10L01**	**10L02**	**10J02**	**0A01**
0	1.015	1.271	1.129	-0.016	0.257	0.477	0.794	0.248	0.162	0.281	0.297	0.362	0.320
15	0.479	0.582	0.589	0.207	0.263	0.368	1.168	0.085	0.016	0.223	0.423	0.635	0.401
30	0.083	0.242	0.215	0.275	-0.064	0.387	1.215	0.326	0.196	0.004	0.240	0.808	0.298
45	0.122	0.403	0.316	0.423	-0.061	0.293	1.425	0.301	0.166	0.055	0.179	1.242	1.088
60	0.302	0.438	0.365	1.832	0.038	0.072	2.250	0.402	0.293	0.210	0.156	2.301	1.393
75	0.401	0.382	0.465	2.974	0.288	0.201	3.451	0.851	0.464	0.208	0.217	3.248	2.033
90	0.786	0.666	0.330	3.678	0.201	0.267	4.218	1.158	0.697	0.212	0.203	4.139	2.328
105	1.060	0.799	0.705	3.867	0.398	0.529	4.723	1.324	0.834	0.394	0.415	4.699	2.666
120	0.843	0.831	0.947	3.405	0.501	0.520	4.077	2.642	1.723	0.506	0.474	4.519	1.973
135	0.742	0.852	0.774	2.486	0.326	0.436	3.194	3.414	2.437	0.388	0.461	3.682	1.144
150	0.489	0.708	0.901	1.075	0.410	0.401	1.956	4.392	3.489	0.318	0.358	2.280	0.599
165	-0.051	0.233	0.456	0.515	0.500	0.391	1.367	5.093	4.126	0.489	0.510	1.320	0.407
180	-0.205	-0.261	0.663	0.552	0.647	0.440	0.919	4.795	3.929	0.581	0.573	0.674	0.343
195	-0.287	-0.092	0.461	0.174	1.064	0.559	0.678	5.085	4.542	1.151	0.803	0.196	0.197
210	-0.179	0.425	0.674	0.076	2.357	1.610	0.275	4.236	4.585	2.324	1.380	0.153	0.139
225	0.305	0.600	0.572	0.044	3.474	2.486	0.174	2.885	3.753	3.234	2.337	0.054	0.104
240	0.703	0.312	0.373	-0.004	4.166	3.761	0.179	2.072	2.780	4.239	3.827	-0.007	0.146
255	0.787	0.337	0.471	0.207	4.811	4.333	0.345	1.483	1.803	4.658	4.243	0.264	0.229
270	0.834	0.367	0.438	0.402	4.405	4.611	0.479	1.040	0.970	4.361	4.595	0.430	0.583
285	0.748	0.396	0.379	0.326	3.647	4.427	0.478	0.606	0.459	3.866	4.663	0.340	0.326
300	1.009	0.567	0.589	0.314	3.321	4.028	0.619	0.432	0.344	3.287	4.233	0.405	0.493
315	1.206	0.770	0.571	0.268	1.954	3.479	0.550	0.488	0.412	1.973	3.422	0.357	0.414
330	1.532	1.221	0.386	0.230	1.345	2.247	0.430	0.374	0.347	1.311	2.013	0.214	0.637
345	1.745	1.597	0.949	0.076	0.395	1.007	0.698	0.316	0.245	0.436	0.987	0.406	0.577

	Port 4 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**8A14**	**8A15**	**8B01**	**8B02**	**8C01**	**8C02**	**8C03**	**8C04**	**8C05**	**8C06**	**8C07**	**8C08**	**8C09**
0	2.830	3.245	0.079	0.309	0.199	0.387	0.250	0.297	0.267	0.259	0.265	0.167	0.329
15	3.584	3.954	0.580	0.675	-0.065	-0.037	-0.058	-0.031	-0.059	-0.019	-0.051	-0.047	0.038
30	4.384	4.889	1.647	1.568	-0.194	-0.240	-0.251	-0.227	-0.217	-0.130	-0.211	-0.104	0.026
45	4.293	4.488	2.408	2.288	-0.081	-0.164	-0.161	-0.157	-0.164	-0.164	-0.185	-0.145	-0.071
60	3.936	3.898	3.008	2.569	-0.045	0.019	-0.009	-0.064	-0.009	0.042	0.057	0.025	0.113
75	3.661	4.020	3.707	3.174	0.922	0.150	0.304	0.441	0.690	0.581	0.666	0.676	0.711
90	2.959	3.034	3.186	2.926	1.376	0.939	1.799	0.886	2.086	0.998	1.850	1.077	1.950
105	2.112	1.895	1.812	1.217	1.135	1.419	1.912	1.389	2.037	1.441	2.603	1.518	2.651
120	1.334	1.253	1.440	1.624	1.486	2.603	2.599	2.709	2.718	2.781	3.180	3.003	3.134
135	0.516	0.538	1.722	2.162	3.636	3.656	3.803	3.377	3.722	3.405	3.990	3.109	3.917
150	0.159	0.205	1.863	1.548	4.811	4.639	4.894	4.085	4.397	3.620	4.217	4.005	4.069
165	-0.003	0.044	0.550	0.478	4.121	4.750	4.379	4.620	4.460	4.155	4.312	4.146	4.334
180	0.167	0.216	0.791	0.419	4.212	5.090	4.696	4.743	4.625	5.085	4.232	4.356	4.469
195	-0.069	-0.020	0.113	0.040	3.320	4.833	4.016	4.283	3.904	4.069	3.773	3.874	3.675
210	-0.155	-0.110	-0.105	-0.088	2.729	4.467	3.454	4.511	3.591	4.359	3.435	4.187	3.746
225	0.039	0.135	0.095	0.052	1.790	4.500	3.288	4.357	3.031	4.269	3.171	4.188	3.350
240	0.156	0.163	0.113	0.153	1.668	3.645	2.734	4.356	2.404	4.028	2.700	3.917	2.494
255	0.176	0.272	0.283	0.217	0.913	2.749	1.605	2.538	1.392	2.714	1.371	2.964	1.666
270	0.669	0.836	0.543	0.410	0.498	1.607	0.857	1.745	0.941	1.945	1.223	1.928	1.142
285	1.070	1.237	1.086	1.037	0.922	1.285	1.098	1.187	1.035	1.230	1.040	1.252	1.138
300	0.786	1.079	0.613	0.808	0.773	0.963	0.965	0.903	0.810	0.856	0.770	0.856	0.831
315	1.012	1.578	0.468	0.581	0.472	0.503	0.534	0.558	0.522	0.596	0.520	0.577	0.645
330	1.493	2.014	0.444	0.486	0.378	0.419	0.405	0.413	0.406	0.431	0.394	0.357	0.451
345	2.348	2.852	0.184	0.402	0.308	0.328	0.327	0.370	0.364	0.372	0.313	0.300	0.404

	Port 5 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**8C10**	**8C11**	**8C12**	**8C13**	**8C14**	**8D01**	**8D02**	**8F01**	**8F02**	**7E01**	**7E02**	**7F01**	**7F02**
0	0.110	0.131	0.096	0.464	0.060	0.093	0.103	0.313	0.394	0.197	0.193	0.079	0.619
15	0.029	0.072	0.017	0.392	0.025	0.029	0.074	0.182	0.342	0.142	0.163	0.045	0.349
30	0.009	0.034	-0.010	0.300	0.099	0.131	0.084	0.023	0.145	0.061	0.037	-0.023	0.122
45	-0.040	-0.010	-0.001	0.346	0.089	0.111	0.125	0.067	0.222	0.205	0.179	0.039	0.155
60	-0.105	-0.072	-0.049	0.335	0.017	-0.008	0.136	0.031	-0.052	0.270	0.508	0.015	0.146
75	0.312	0.422	0.372	0.794	0.173	0.073	0.481	0.333	0.288	0.306	0.748	0.370	0.302
90	0.949	2.088	0.928	2.323	0.566	0.294	0.536	0.368	0.279	0.358	0.881	0.279	0.388
105	1.759	2.504	1.586	2.932	0.994	0.759	0.956	0.439	0.438	0.937	1.324	0.548	0.586
120	2.809	3.484	2.614	3.657	1.308	1.031	1.249	0.571	0.498	0.953	1.415	0.491	0.575
135	2.833	4.258	2.901	4.286	1.802	1.301	1.516	0.369	0.492	1.497	1.982	0.396	0.593
150	3.624	3.954	3.500	4.228	2.266	1.654	2.481	0.376	0.429	1.888	2.716	0.278	0.518
165	4.022	4.214	3.589	4.449	2.619	1.704	2.511	0.322	0.151	2.266	3.073	0.207	0.329
180	3.858	4.326	3.685	4.382	3.255	2.316	3.190	0.516	0.180	2.780	3.481	0.181	0.251
195	4.081	3.814	4.545	4.740	4.307	3.561	4.460	1.026	0.285	4.028	4.002	0.825	0.282
210	3.866	3.570	3.878	4.365	4.136	3.790	4.694	2.254	1.182	4.107	3.894	2.065	0.856
225	3.900	3.314	3.859	3.779	4.128	3.926	4.679	3.054	2.201	3.961	4.071	2.628	2.142
240	3.306	2.639	2.941	2.703	3.313	4.403	4.302	4.123	3.244	3.760	3.432	3.694	2.677
255	2.728	1.930	1.452	1.262	2.654	4.765	4.127	4.416	4.459	3.449	2.604	3.852	3.683
270	1.168	0.919	0.356	0.659	1.772	4.615	3.762	4.301	4.108	3.117	2.179	3.719	4.037
285	0.934	0.825	0.776	1.032	1.149	3.495	2.410	4.144	4.870	1.672	1.383	3.103	4.284
300	0.762	0.734	0.801	1.117	1.211	2.148	1.031	3.085	3.702	0.739	0.519	2.813	3.617
315	0.408	0.461	0.511	0.884	0.782	0.512	0.379	2.509	3.404	0.413	0.418	1.799	2.921
330	0.447	0.431	0.371	0.709	0.270	0.287	0.315	1.064	2.343	0.368	0.379	0.883	2.198
345	0.322	0.324	0.236	0.602	0.179	0.233	0.270	0.513	1.067	0.265	0.324	0.403	1.157

	Port 6 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**6C01**	**6C02**	**6C03**	**6C04**	**6C05**	**7C01**	**7C02**	**7C03**	**7C04**	**7C06**	**7C07**	**7C08**	**7D01**
0	0.218	0.136	0.286	0.406	0.074	0.237	0.226	0.285	0.321	0.131	0.101	0.031	0.059
15	-0.103	-0.168	-0.086	0.260	-0.066	-0.114	-0.067	-0.015	-0.023	-0.051	-0.004	0.017	-0.087
30	-0.101	-0.155	-0.164	0.233	0.047	-0.123	-0.109	-0.159	-0.160	-0.051	0.013	0.075	-0.017
45	-0.137	-0.168	-0.150	0.214	0.003	-0.084	-0.080	-0.176	-0.177	-0.090	-0.016	-0.027	0.025
60	-0.288	-0.329	-0.221	0.314	0.098	-0.302	-0.233	-0.250	-0.226	-0.101	-0.011	0.005	0.009
75	0.230	0.276	0.821	1.372	-0.051	0.215	0.257	0.273	0.407	0.409	0.197	0.031	-0.004
90	0.484	0.657	1.197	1.810	0.140	0.492	0.556	0.730	0.927	0.887	0.886	0.333	0.117
105	0.528	0.638	1.073	1.673	0.855	0.626	0.706	0.941	1.106	1.446	1.410	0.785	0.615
120	1.028	1.700	2.229	2.953	1.036	0.878	2.182	2.142	2.364	2.653	2.340	1.138	0.876
135	2.761	3.017	3.231	3.030	1.605	3.094	3.418	3.332	2.948	2.593	2.586	1.685	1.108
150	4.266	3.930	3.183	3.634	2.387	4.308	3.865	3.513	3.317	3.792	3.540	2.336	1.699
165	3.510	3.953	3.919	4.057	2.631	4.153	4.512	4.122	4.435	3.870	3.821	2.756	1.687
180	3.447	4.306	4.310	4.413	3.122	3.808	4.583	4.460	4.565	3.865	3.937	3.070	2.171
195	2.967	4.018	3.838	4.208	3.356	3.025	4.564	4.088	4.144	4.150	4.454	3.651	3.178
210	2.697	3.282	3.586	3.961	3.575	2.813	3.992	3.905	4.007	3.762	3.910	3.996	3.771
225	1.697	2.714	2.951	3.203	3.447	1.852	3.772	3.722	3.568	3.777	3.608	3.734	3.686
240	1.190	1.793	2.069	2.791	3.058	1.345	3.430	2.911	3.029	2.992	2.822	3.116	4.354
255	0.574	1.114	1.419	1.197	2.110	0.447	2.055	2.112	2.158	2.315	1.784	2.478	4.400
270	0.516	0.745	0.812	0.698	1.264	0.490	1.520	1.420	1.263	1.142	0.499	1.569	4.317
285	0.801	0.853	0.772	0.843	0.737	0.861	1.126	1.074	0.945	0.795	0.663	1.287	2.951
300	0.785	0.673	0.595	0.910	0.821	0.707	0.879	0.728	0.723	0.689	0.712	1.045	1.607
315	0.541	0.541	0.500	0.748	0.535	0.593	0.593	0.500	0.496	0.439	0.442	0.721	0.478
330	0.370	0.368	0.355	0.667	0.245	0.415	0.434	0.415	0.356	0.337	0.348	0.251	0.249
345	0.277	0.282	0.260	0.564	0.178	0.267	0.355	0.251	0.282	0.262	0.294	0.187	0.187

	Port 7 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**6A01**	**6A02**	**6A03**	**6A04**	**6A05**	**7A01**	**7A02**	**7A03**	**7A04**	**7A05**	**7A06**	**7C05**	**00J01**
0	1.558	2.978	3.668	3.837	3.251	3.600	3.726	4.109	3.981	4.539	3.115	0.160	0.137
15	1.431	3.139	3.288	3.501	3.681	4.085	3.423	3.920	3.726	4.386	3.842	-0.007	-0.004
30	1.338	2.933	3.225	3.912	4.193	3.979	3.695	3.745	3.896	4.206	4.237	-0.113	0.194
45	1.523	2.804	2.847	2.829	3.848	3.666	3.803	3.473	3.581	3.703	4.031	-0.189	0.372
60	1.645	2.384	2.479	2.528	3.338	3.197	3.108	2.958	3.300	3.341	3.550	-0.094	0.402
75	1.672	2.679	2.162	2.057	3.212	2.863	2.492	2.661	2.660	2.759	3.552	0.334	0.256
90	1.720	2.462	1.854	1.797	2.807	2.469	2.256	2.037	2.116	2.021	2.945	0.877	0.205
105	1.635	1.756	1.433	1.285	1.948	1.805	1.569	1.579	1.353	1.457	1.943	1.195	0.420
120	1.841	1.071	0.945	0.884	1.125	1.111	1.111	0.977	0.984	1.069	1.119	2.358	1.191
135	0.664	0.517	0.497	0.489	0.482	0.572	0.560	0.554	0.617	0.633	0.510	3.251	1.058
150	0.292	0.242	0.237	0.077	0.058	0.276	0.249	0.180	0.098	0.182	0.298	3.284	0.646
165	0.198	0.115	0.087	-0.060	0.045	0.176	0.164	-0.028	-0.027	-0.033	0.133	4.453	0.140
180	0.056	0.071	0.153	0.031	0.041	0.178	0.207	0.072	0.030	0.017	0.095	3.831	-0.185
195	0.043	0.009	0.096	0.069	0.011	0.095	0.156	0.114	0.042	0.009	0.006	4.423	-0.119
210	0.069	0.057	0.120	-0.037	-0.138	0.101	0.173	-0.034	-0.086	-0.108	-0.167	3.806	0.172
225	0.184	0.160	0.224	0.142	0.130	0.159	0.231	0.236	0.243	0.170	0.064	3.843	0.363
240	0.109	-0.025	0.103	0.198	0.100	0.043	0.144	0.225	0.219	0.246	0.124	3.150	0.751
255	0.250	0.066	0.271	0.271	0.204	0.080	0.225	0.370	0.416	0.284	0.221	2.113	1.167
270	0.460	0.303	0.496	0.679	0.634	0.298	0.415	0.648	0.705	0.731	0.797	1.195	1.353
285	0.509	0.273	0.620	1.308	1.052	0.224	0.368	0.924	1.408	1.434	1.021	0.905	1.605
300	0.785	0.596	2.430	2.971	0.910	0.854	2.252	2.641	2.120	2.194	0.911	0.780	1.879
315	1.250	1.683	3.273	3.490	0.935	2.226	3.201	3.097	2.957	3.003	0.826	0.514	1.819
330	1.986	2.633	3.355	3.620	1.511	3.024	3.518	3.443	3.510	3.548	1.573	0.436	1.553
345	1.853	2.832	3.430	3.791	2.400	3.411	3.613	3.740	3.735	3.572	2.292	0.412	1.569

	Port 8 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**1A01**	**1A02**	**1A03**	**1A04**	**2A01**	**2C01**	**2C02**	**2C03**	**2C04**	**2C05**	**3A01**	**3A02**	**3A03**
0	2.137	2.594	3.001	2.205	2.570	0.134	0.074	0.051	-0.013	-0.040	2.787	3.085	2.673
15	2.044	2.536	2.897	2.731	3.118	0.023	-0.010	-0.037	-0.004	0.052	2.780	3.227	3.539
30	2.479	3.022	3.133	2.551	3.068	-0.223	-0.264	-0.239	-0.143	-0.124	3.238	3.422	3.724
45	2.290	2.577	2.680	2.494	2.989	-0.224	-0.241	-0.249	-0.075	0.022	2.883	2.640	3.346
60	2.054	2.368	2.352	2.115	2.492	-0.257	-0.243	-0.035	0.248	0.640	2.640	2.610	2.846
75	2.414	2.456	2.257	2.146	2.689	0.315	0.469	1.084	1.291	1.424	2.846	2.333	2.937
90	1.957	2.023	1.959	2.186	2.887	0.757	1.001	1.247	1.153	1.144	2.389	2.054	2.691
105	1.526	1.684	1.507	1.699	1.828	0.436	0.449	0.760	1.082	1.495	1.754	1.618	2.016
120	1.125	1.143	1.107	1.684	1.458	0.679	1.426	1.888	1.761	1.616	1.393	1.048	1.145
135	0.618	0.522	0.444	0.353	0.423	1.274	2.583	2.245	1.750	1.539	0.609	0.538	0.443
150	0.458	0.376	0.250	0.230	0.137	1.432	2.925	2.263	2.325	2.129	0.475	0.186	0.145
165	0.173	0.121	0.016	-0.047	-0.033	1.257	3.088	3.529	2.864	2.050	0.175	0.057	-0.042
180	0.193	0.055	0.035	0.016	0.030	1.808	3.455	3.060	2.992	2.253	0.134	0.134	0.057
195	0.105	0.011	-0.044	-0.072	-0.075	1.555	3.354	3.077	3.049	2.251	0.093	0.128	-0.052
210	0.145	0.119	0.024	-0.049	0.006	0.968	2.494	2.732	2.697	2.308	0.149	0.147	0.000
225	0.200	0.153	0.076	0.020	0.037	0.811	1.746	2.225	2.206	2.103	0.153	0.160	0.055
240	0.320	0.190	0.280	0.176	0.166	0.676	1.376	1.575	2.051	1.635	0.217	0.304	0.202
255	0.478	0.348	0.376	0.332	0.208	0.657	1.144	1.169	1.335	0.905	0.399	0.395	0.228
270	0.755	0.729	0.804	0.750	0.778	1.045	1.045	0.969	0.781	0.685	0.660	0.779	0.668
285	0.780	0.771	1.161	1.080	1.093	0.903	0.881	0.775	0.661	0.489	0.657	0.923	1.151
300	1.190	1.142	1.537	1.096	1.047	0.889	0.898	0.759	0.635	0.491	1.135	1.422	1.025
315	1.584	1.721	2.211	0.869	1.010	0.544	0.596	0.565	0.448	0.404	1.590	2.325	0.972
330	2.080	2.115	2.316	1.351	1.646	0.455	0.458	0.391	0.355	0.308	2.038	2.243	1.880
345	2.151	2.524	2.820	1.886	2.278	0.268	0.236	0.199	0.114	0.104	2.522	3.066	2.331

Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
	Port 9 Positive Peak Pressure Coefficient												
Tap	**3B01**	**3B02**	**3C01**	**3C02**	**4A01**	**4C01**	**4C02**	**4C04**	**4C05**	**5A01**	**5A02**	**5A03**	**5B01**
0	0.297	0.319	0.196	0.094	2.850	0.194	0.149	0.157	0.076	3.810	3.918	2.913	0.468
15	1.554	1.167	-0.027	0.119	4.005	-0.082	-0.052	0.131	0.083	3.375	3.914	3.976	0.891
30	2.515	1.841	-0.262	0.032	3.743	-0.222	-0.264	-0.096	-0.097	3.647	3.883	3.981	1.866
45	2.901	2.105	-0.231	0.587	3.378	-0.240	-0.267	-0.185	0.386	3.072	3.464	3.556	2.907
60	3.095	2.177	-0.180	1.229	3.517	-0.198	-0.222	0.328	0.996	3.066	3.037	3.419	3.208
75	2.939	2.159	-0.007	1.359	3.053	0.096	0.158	1.507	0.722	2.282	2.346	3.279	3.161
90	2.200	1.695	0.660	1.062	2.830	0.492	0.626	1.204	0.559	2.232	2.127	3.236	2.871
105	1.148	0.954	0.481	1.874	2.386	0.433	0.483	1.211	1.485	1.649	1.649	2.548	1.096
120	0.459	0.483	0.559	2.010	1.454	1.217	1.773	2.109	1.654	1.053	0.960	1.375	0.637
135	0.980	0.857	2.831	1.717	0.568	3.549	3.442	2.463	1.626	0.421	0.352	0.606	0.704
150	0.442	0.466	3.656	2.115	0.163	4.021	3.463	2.692	2.360	0.205	0.084	0.155	0.463
165	0.019	0.160	1.651	2.458	-0.019	2.381	3.500	3.442	2.651	0.040	-0.031	-0.001	0.255
180	0.036	-0.046	2.235	2.144	-0.058	2.990	3.704	3.442	2.555	0.144	-0.020	0.014	0.297
195	-0.085	-0.153	1.971	2.364	0.030	2.880	3.352	3.023	2.691	0.137	-0.021	0.068	0.284
210	-0.159	-0.163	1.110	2.054	-0.107	1.845	2.716	2.990	2.824	0.063	-0.048	-0.065	-0.095
225	0.047	-0.015	0.760	1.966	0.025	1.222	2.308	2.438	2.934	0.121	0.064	0.025	-0.030
240	0.294	0.209	0.740	1.584	0.195	1.045	1.390	1.889	1.856	0.266	0.316	0.217	0.223
255	1.178	1.367	0.613	0.760	0.240	0.643	1.144	1.154	1.236	0.441	0.421	0.306	0.411
270	2.026	2.097	1.514	0.819	0.923	1.200	0.920	0.737	1.067	0.732	0.688	0.791	0.808
285	1.305	1.372	0.909	0.822	1.063	0.841	0.916	0.584	0.719	0.790	1.130	1.047	1.126
300	0.921	1.055	0.961	0.531	1.265	0.955	0.903	0.655	0.620	1.896	1.852	1.470	0.870
315	0.459	0.576	0.537	0.382	1.150	0.530	0.519	0.515	0.393	2.958	3.607	1.276	0.448
330	0.299	0.468	0.359	0.232	1.825	0.384	0.413	0.381	0.260	2.842	3.219	1.701	0.312
345	0.107	0.306	0.256	0.043	2.153	0.298	0.252	0.206	0.048	3.783	3.766	2.224	0.129

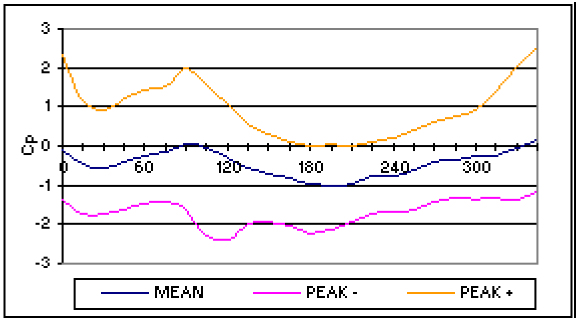
	Port 10 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**5B02**	**5C01**	**5C02**	**5C03**	**5C04**	**5D01**	**5F01**	**5F02**	**6D01**	**6D02**	**6F01**	**6F02**	**7B01**
0	0.203	0.154	0.128	0.121	0.025	-0.009	-0.084	0.487	-0.026	-0.044	-0.086	0.294	1.149
15	0.564	-0.082	-0.179	-0.153	-0.034	-0.172	-0.086	0.204	-0.207	-0.119	-0.106	0.176	2.123
30	1.538	-0.334	-0.357	-0.281	0.025	-0.144	-0.129	0.033	-0.135	-0.010	-0.172	0.012	3.326
45	1.953	-0.270	-0.267	-0.231	0.001	0.037	-0.075	-0.083	-0.065	0.046	-0.088	-0.023	4.170
60	2.269	-0.332	-0.243	0.108	0.227	0.038	0.035	-0.034	-0.062	0.447	-0.003	-0.023	3.805
75	2.300	0.058	0.495	1.084	0.336	-0.004	0.107	0.188	-0.077	0.618	0.187	0.234	4.196
90	1.881	0.322	0.717	0.999	0.417	0.184	0.411	0.241	0.091	0.503	0.242	0.299	3.686
105	0.551	0.397	0.771	1.280	1.032	0.654	0.637	0.429	0.555	0.831	0.489	0.440	2.145
120	0.494	1.029	2.237	2.680	1.165	0.829	0.826	0.584	0.783	1.052	0.566	0.553	1.164
135	0.212	2.617	3.056	2.651	1.745	1.239	0.574	0.229	0.985	1.296	0.384	0.273	1.322
150	0.305	3.942	2.804	2.991	2.322	1.844	0.927	0.317	1.596	1.885	0.397	0.262	2.001
165	0.119	2.781	3.864	3.708	2.540	1.760	0.732	0.144	1.680	1.982	0.267	0.133	0.553
180	0.332	3.195	3.988	4.191	3.266	2.255	0.758	0.099	2.568	2.787	0.413	0.030	0.663
195	0.022	2.875	3.534	3.639	3.294	2.509	1.370	0.111	2.696	3.025	1.236	0.089	0.020
210	-0.060	2.406	2.948	3.432	3.247	2.827	1.940	0.457	3.084	3.368	1.644	0.445	-0.058
225	-0.018	1.564	2.655	2.766	3.867	2.858	2.396	1.076	3.289	3.740	2.703	1.018	0.003
240	0.091	1.093	1.868	2.144	2.718	3.305	2.085	1.541	4.075	3.461	2.898	1.403	0.114
255	0.238	0.672	1.009	1.238	1.861	3.495	2.262	1.937	4.375	3.945	3.082	1.892	0.237
270	0.500	0.618	0.828	0.797	1.342	2.559	1.953	1.907	3.202	2.625	2.399	2.306	0.725
285	0.974	0.890	0.783	0.701	0.814	1.610	1.439	2.189	2.274	1.632	1.471	2.402	0.977
300	0.695	0.718	0.641	0.643	0.882	0.980	1.106	2.046	1.226	0.470	0.910	2.343	0.610
315	0.449	0.494	0.501	0.566	0.473	0.358	0.754	1.807	0.365	0.368	0.739	2.032	0.353
330	0.327	0.341	0.365	0.275	0.211	0.221	0.521	1.474	0.175	0.189	0.460	1.502	0.309
345	0.254	0.257	0.232	0.208	0.089	0.068	0.145	1.006	0.041	0.079	0.111	0.819	0.532

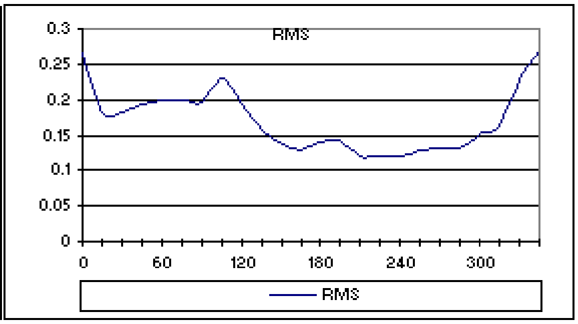
	Port 11 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**0C01**	**0B02**	**0B01**	**0A04**	**0RR1**	**0RR2**	**0RR3**	**0RR4**	**0RR5**	**0RR6**	**0RR7**	**0RR8**	**0D01**
0	1.004	0.510	0.015	-0.032	-0.014	0.218	0.366	0.581	0.715	0.651	0.774	0.702	0.213
15	1.025	0.137	-0.139	-0.476	0.105	0.430	0.436	0.324	0.588	0.343	0.523	0.382	0.300
30	0.596	0.070	-0.152	-0.602	0.267	0.197	0.469	0.334	0.444	0.141	0.433	0.208	0.291
45	0.572	0.111	-0.396	-0.447	0.546	0.284	0.685	0.158	0.418	0.360	0.337	0.127	0.561
60	0.603	0.029	-0.440	0.114	0.738	0.497	0.701	0.179	0.844	0.549	0.518	0.482	0.689
75	1.208	0.739	0.065	0.835	1.047	0.699	1.428	0.871	1.423	0.977	1.175	0.821	1.224
90	1.688	1.549	1.258	1.699	1.769	2.007	1.733	1.846	1.763	1.788	1.591	1.759	1.658
105	1.531	1.766	1.557	2.095	1.746	2.554	1.842	2.174	1.759	2.002	1.567	1.903	1.879
120	1.606	1.755	1.337	2.045	1.641	2.451	1.672	2.054	1.639	1.612	1.546	1.956	1.996
135	1.640	1.569	1.195	2.043	1.257	2.204	1.341	1.743	1.487	1.676	1.504	1.790	2.208
150	0.911	1.128	0.831	2.024	1.122	1.636	1.213	1.299	1.078	1.161	1.402	1.389	2.653
165	0.656	0.555	0.294	1.336	0.798	0.658	0.699	0.619	0.937	0.724	0.817	0.842	2.339
180	-0.157	0.450	0.315	1.279	0.940	0.942	0.948	0.777	0.891	0.893	0.365	0.514	2.286
195	-0.247	0.353	0.039	0.811	0.558	0.597	0.464	0.523	0.380	0.490	0.207	0.479	2.495
210	-0.255	0.327	0.139	0.660	0.463	0.516	0.498	0.349	0.292	0.454	0.284	0.707	1.610
225	0.099	0.288	0.412	0.865	0.476	0.781	0.413	0.501	0.431	0.531	0.381	0.852	1.047
240	0.278	0.232	0.567	0.867	0.493	1.000	0.507	0.570	0.558	0.579	0.424	0.776	0.813
255	0.447	0.518	0.613	0.926	0.677	1.172	0.687	0.721	0.633	0.696	0.618	0.998	0.367
270	1.153	1.181	1.036	1.219	1.203	1.585	1.339	1.314	1.287	1.310	1.014	1.569	0.721
285	1.391	1.404	1.102	1.416	1.367	1.582	1.387	1.467	1.353	1.520	1.336	1.447	1.098
300	1.467	1.151	0.911	1.372	1.230	1.775	1.194	1.233	1.322	1.244	1.310	1.270	0.798
315	1.282	0.887	0.650	0.736	0.875	1.368	1.040	0.983	1.109	1.055	1.175	1.113	0.550
330	1.005	0.754	0.229	0.295	0.572	0.930	0.784	0.849	0.882	0.802	0.862	0.892	0.243
345	1.018	0.739	0.096	-0.080	0.258	0.449	0.697	0.894	0.714	0.971	0.952	0.705	0.278

	Port 12 Positive Peak Pressure Coefficient												
Angle	Chan #4	Chan #5	Chan #6	Chan #7	Chan #8	Chan #9	Chan #10	Chan #11	Chan #12	Chan #13	Chan #14	Chan #15	Chan #16
Tap	**0RL1**	**0RL2**	**0RL3**	**0RL4**	**0RL5**	**0RL6**	**0RL7**	**0RL8**	**0RL13**	**0RL12**	**0RL11**	**0RL10**	**0RL9**
0	0.093	0.353	0.178	0.085	0.457	0.194	0.639	0.346	0.393	0.787	0.034	0.409	2.930
15	0.139	0.195	-0.016	0.062	0.133	0.216	0.388	0.221	0.263	0.316	-0.003	0.449	2.712
30	0.069	0.201	0.477	0.263	0.384	0.398	0.475	0.509	0.317	0.456	0.114	0.376	2.297
45	0.730	0.900	0.597	0.511	0.430	0.549	0.600	0.625	0.540	1.296	0.142	0.806	2.438
60	0.691	0.887	0.680	0.512	0.626	0.580	0.497	0.643	0.475	0.869	0.340	1.022	2.941
75	1.558	1.499	1.732	1.462	1.204	1.134	1.080	0.934	0.805	0.953	0.928	1.768	2.490
90	2.326	2.010	2.845	2.219	1.970	1.707	1.472	1.307	1.355	1.577	1.301	2.390	3.038
105	2.128	1.886	2.897	2.024	2.121	1.823	1.685	1.552	1.602	1.973	2.280	2.273	2.805
120	1.733	1.489	2.280	1.779	2.009	1.728	1.581	1.503	1.609	2.291	3.331	1.715	2.345
135	0.884	0.867	1.477	1.296	1.923	1.494	1.595	1.286	1.783	2.661	4.555	0.593	0.753
150	0.722	0.734	0.968	0.811	1.472	1.189	1.933	1.380	1.637	2.754	4.923	0.386	0.434
165	0.833	0.856	0.968	0.798	0.909	0.870	1.721	1.117	1.738	3.368	5.587	0.246	0.366
180	0.517	0.736	0.982	0.683	1.135	0.425	1.371	0.550	0.990	2.977	5.269	0.128	0.206
195	0.532	0.973	0.694	0.743	0.997	0.843	0.919	0.522	1.185	2.097	4.739	0.018	0.140
210	0.231	0.805	0.456	0.784	0.916	0.761	0.768	0.646	1.385	1.414	2.968	0.089	0.109
225	0.155	0.487	0.323	0.881	0.871	0.766	0.933	0.817	1.066	0.860	2.141	0.066	0.165
240	0.294	0.855	0.133	0.457	0.656	0.559	0.833	0.609	0.844	0.415	0.500	-0.052	0.090
255	0.313	0.561	0.181	0.381	0.713	0.708	0.951	0.787	0.687	0.641	0.244	0.114	0.225
270	0.417	0.542	0.366	0.575	0.880	0.774	1.106	0.970	0.915	0.754	0.595	0.184	0.244
285	0.361	0.570	0.396	0.741	0.393	0.809	0.892	0.957	0.854	0.512	0.487	0.218	0.317
300	0.411	0.442	0.376	0.638	0.377	0.677	0.685	0.792	0.608	0.485	0.497	0.372	0.437
315	0.461	0.623	0.433	0.526	0.497	0.551	0.618	0.598	0.412	0.422	0.316	0.269	0.276
330	0.633	0.596	0.233	0.482	0.506	0.512	0.648	0.631	0.351	0.401	0.119	0.556	1.168
345	0.296	0.272	0.162	0.285	0.600	0.510	0.742	0.764	0.479	0.662	0.262	0.587	2.154

Port 1

Tap #8A01 Chan #4





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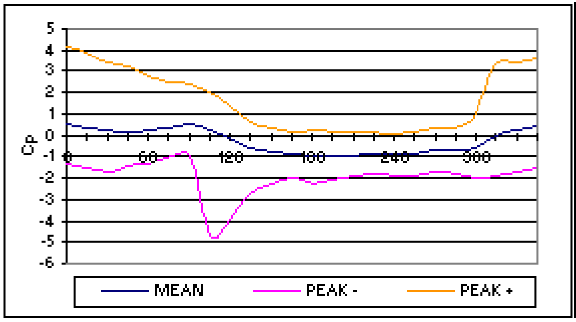

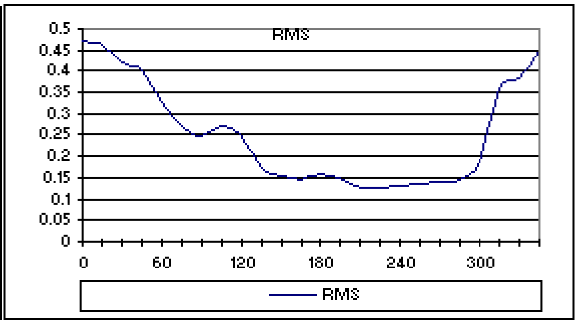

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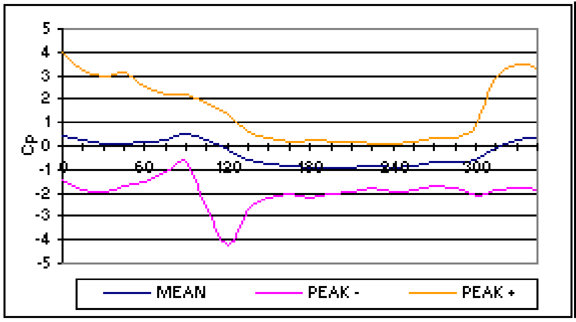

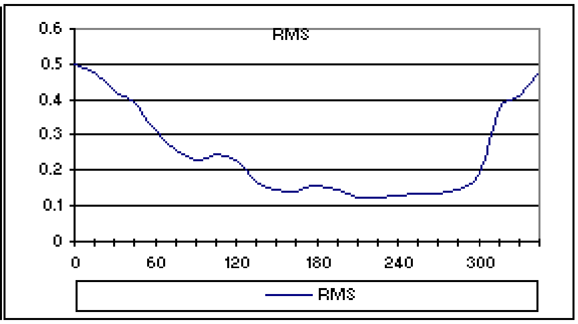

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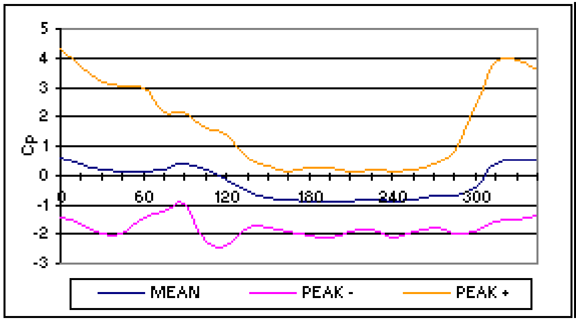

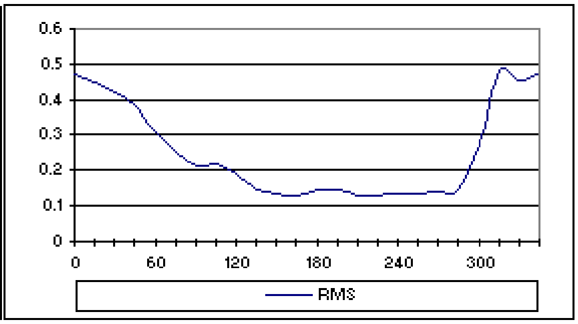

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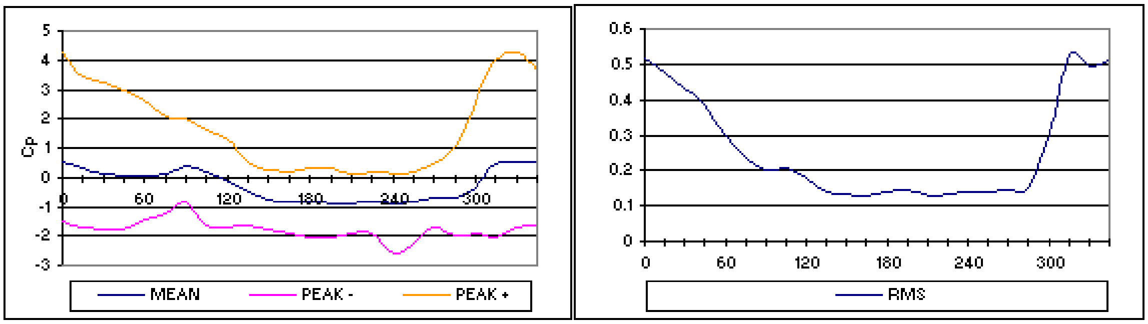

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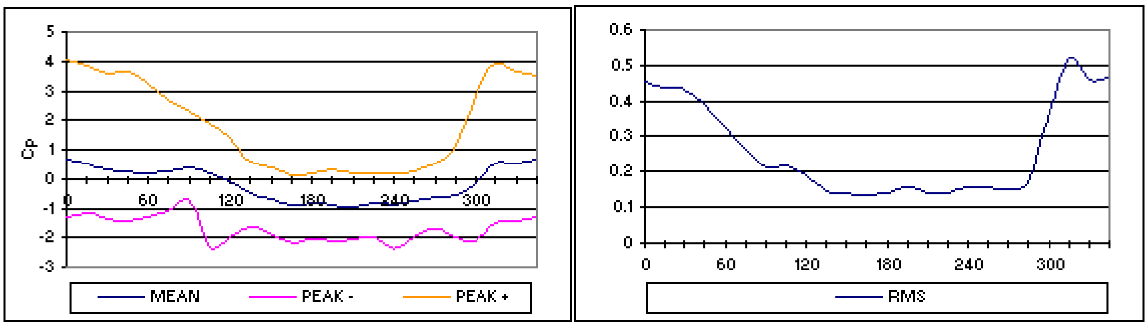

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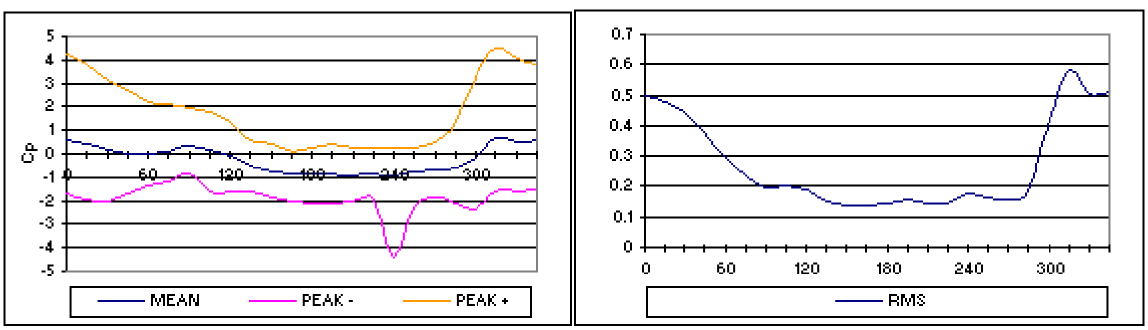
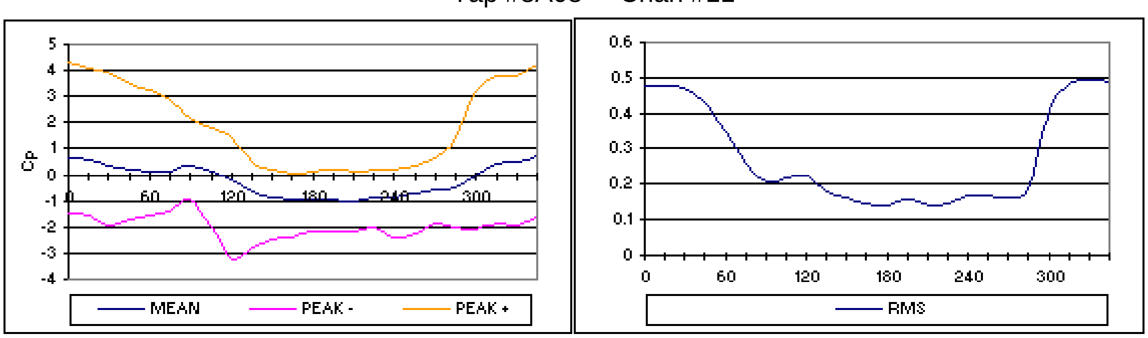
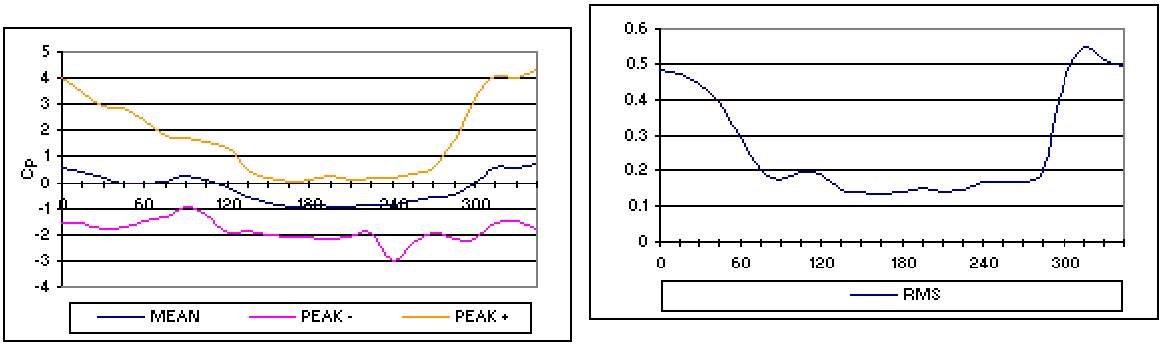


Tap #8A08 Chan #11



Tap #8A09 Chan #12



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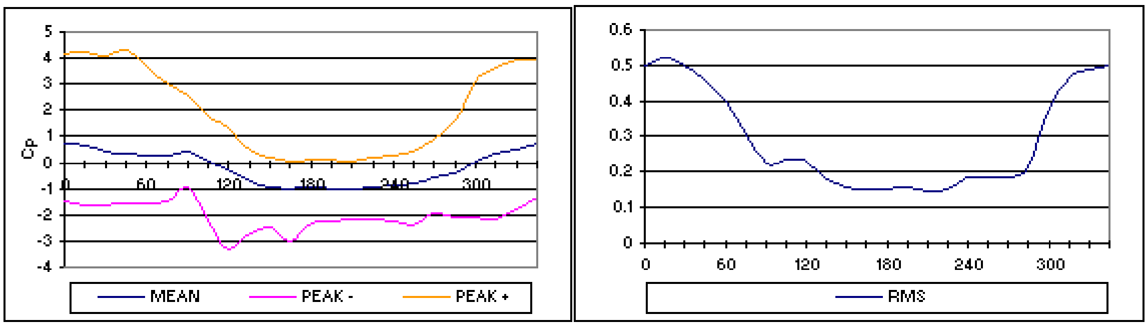

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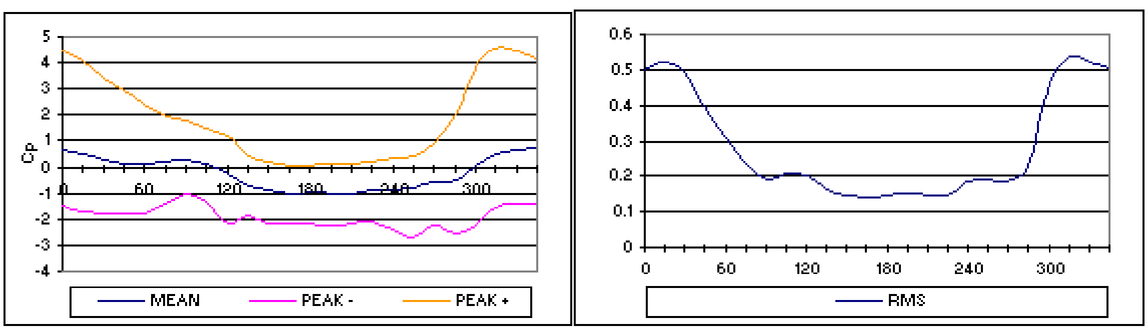

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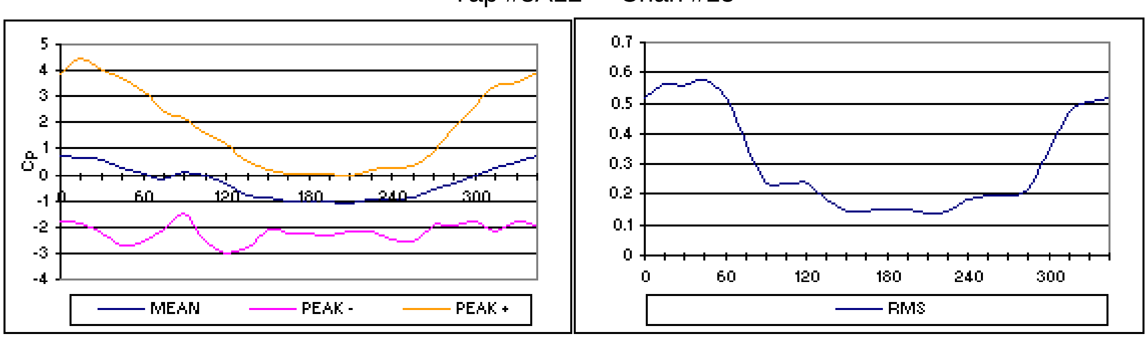

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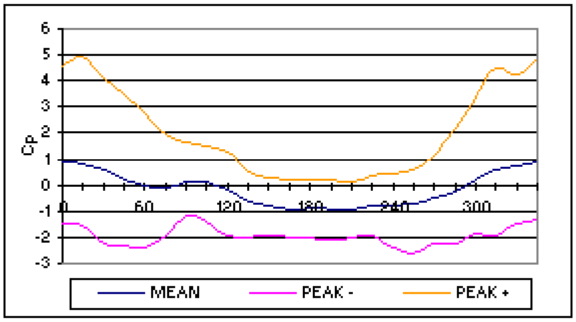
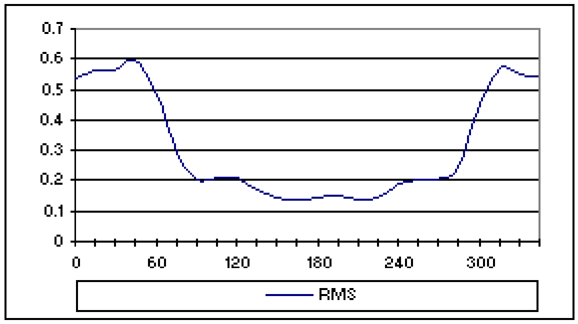
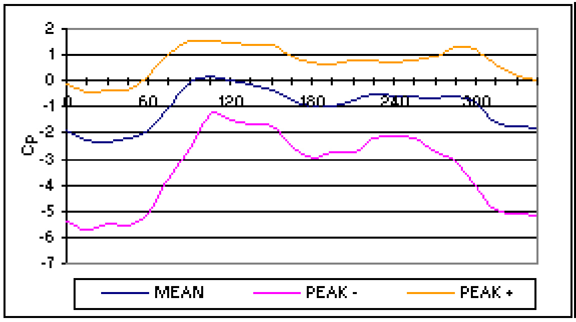
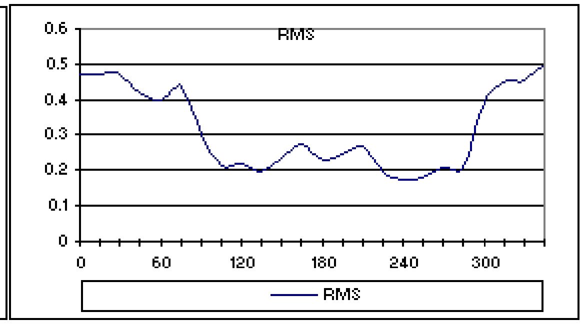




Port 2

Tap #0A03 Chan #4





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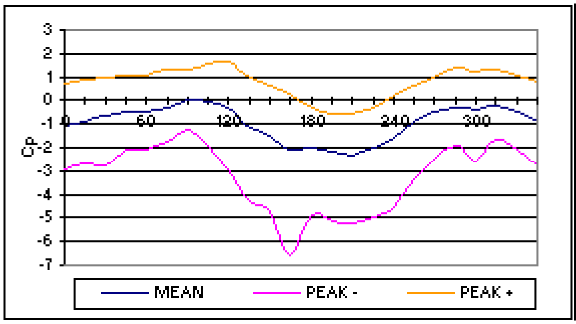

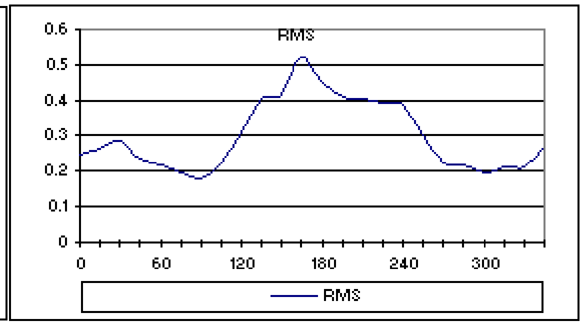

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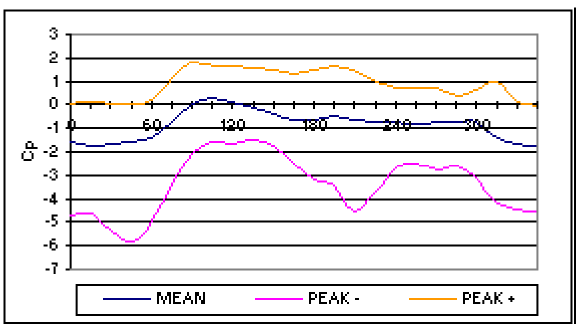

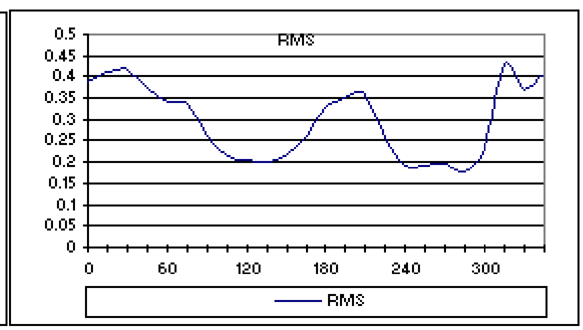

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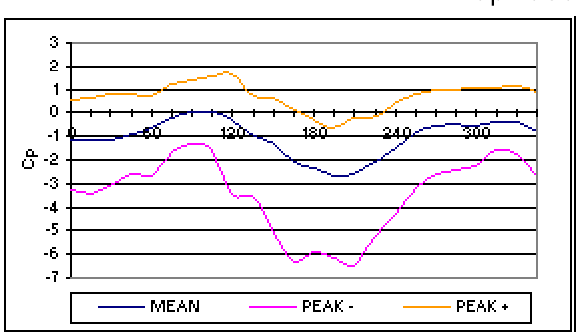
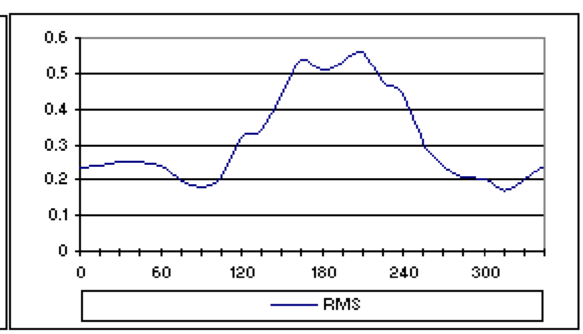
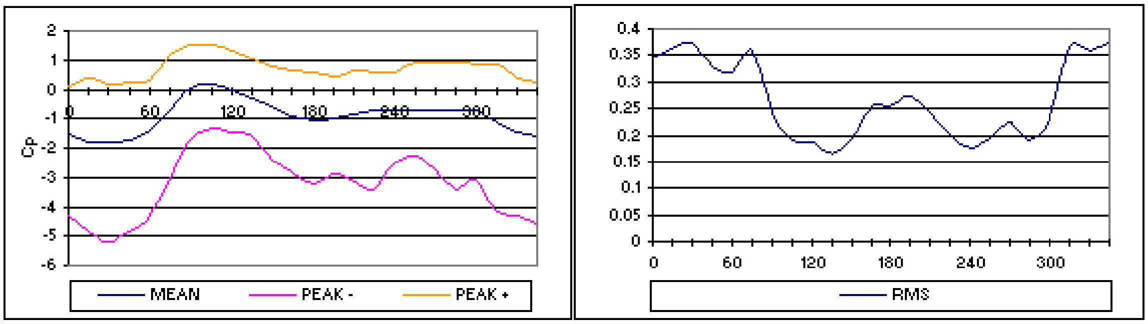




Tap #0RM1 Chan #8



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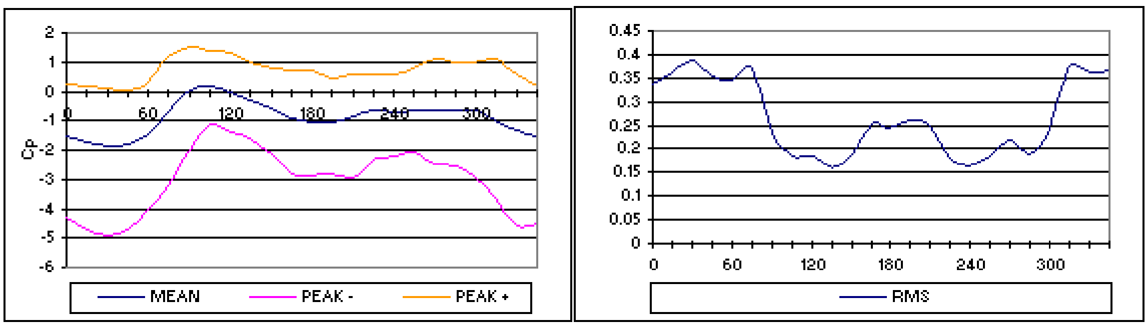

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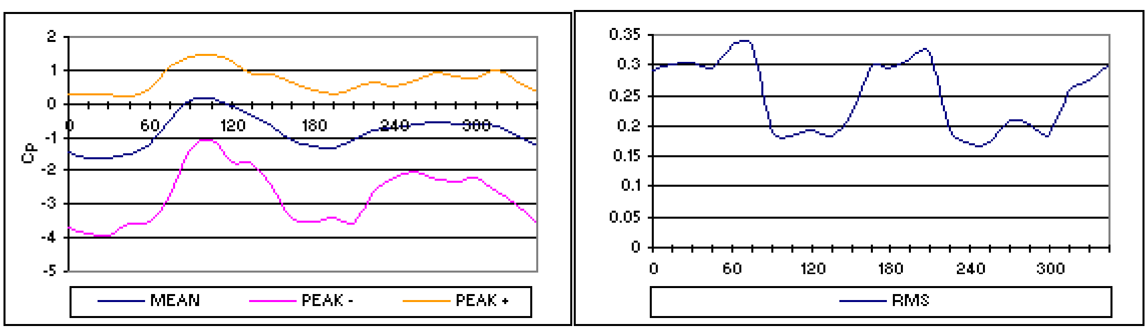

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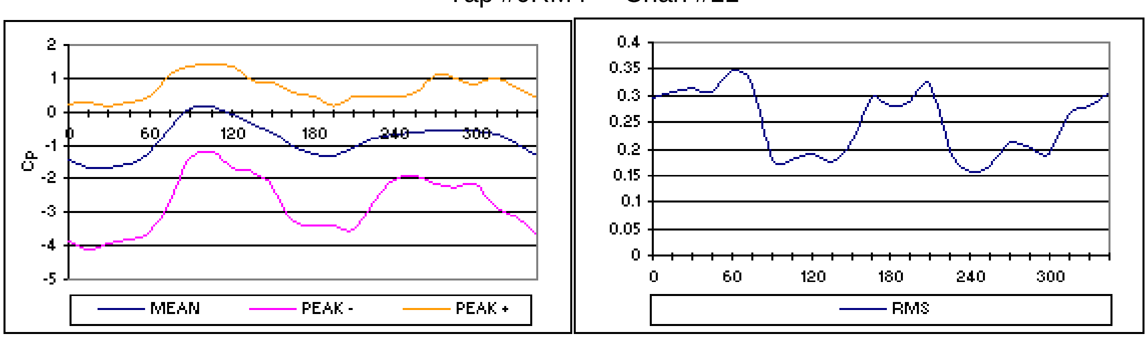

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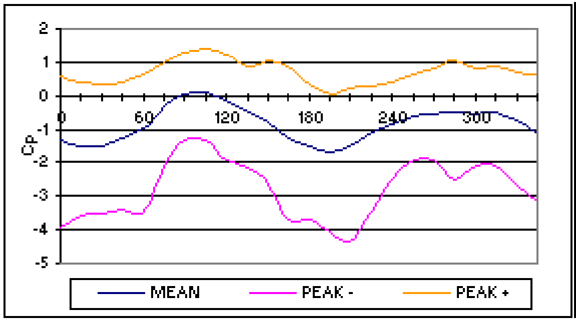
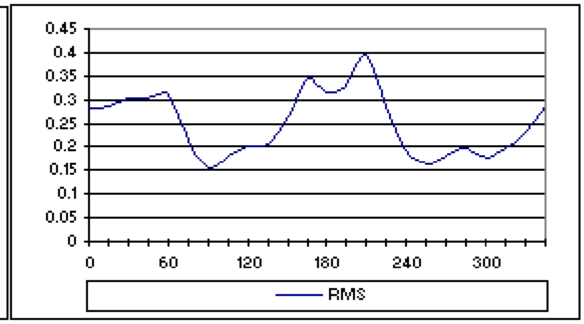
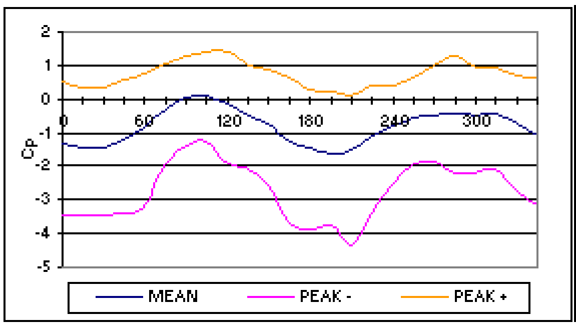
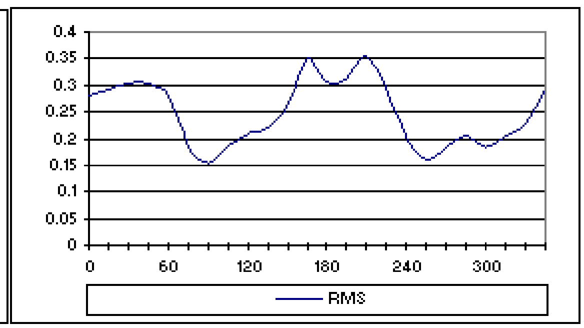




Tap #0RM6 Chan #13





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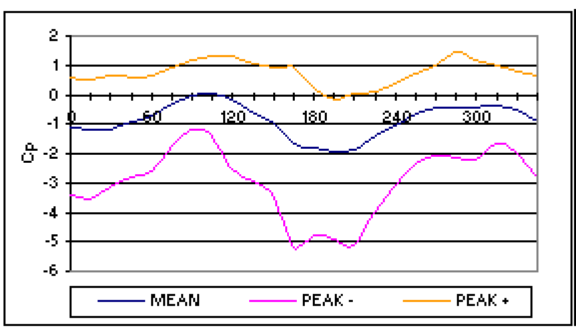

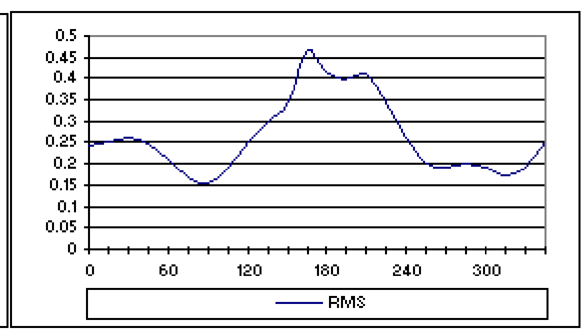

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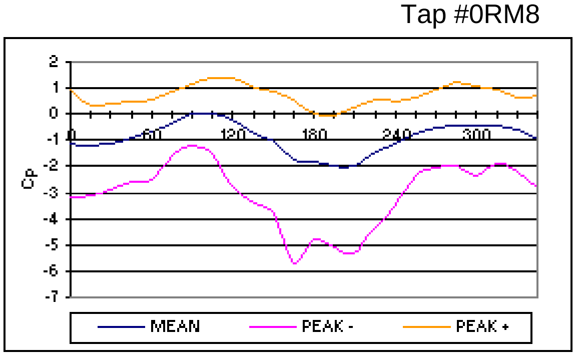
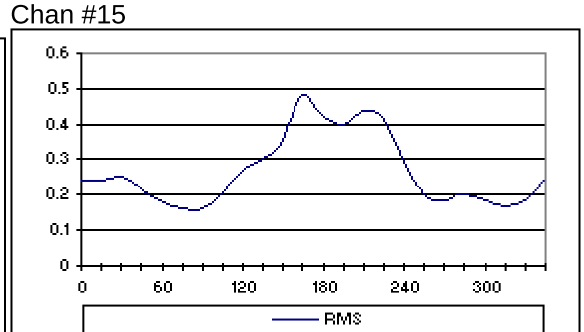
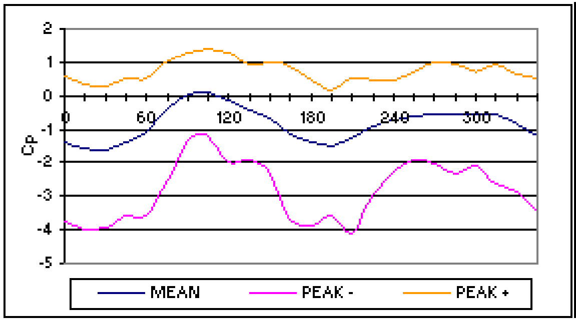
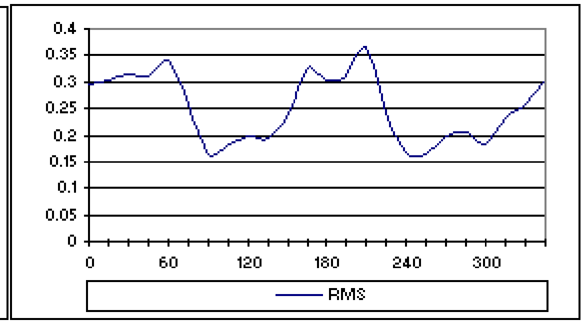




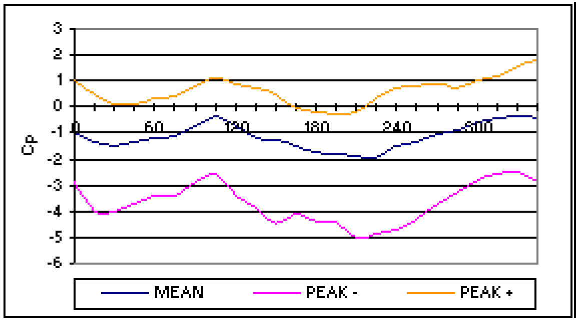
Tap #0RM9   Chan #16

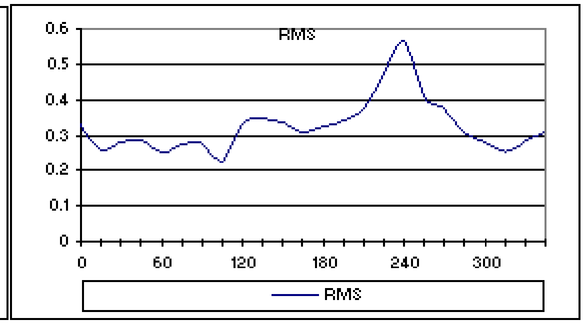




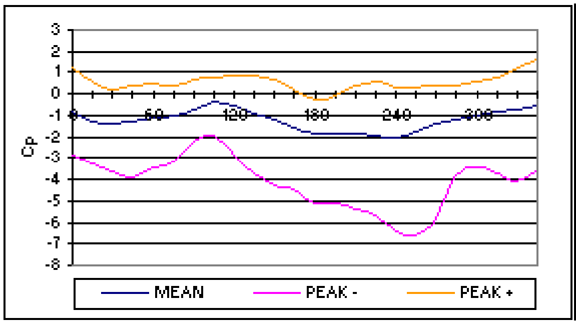
Port 3

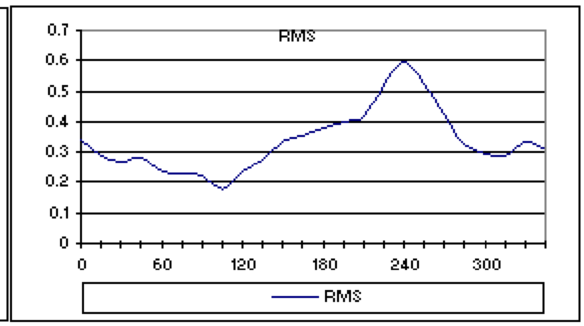
Tap #00K01 Chan #4



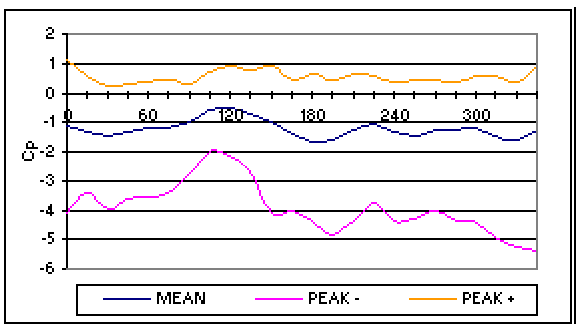


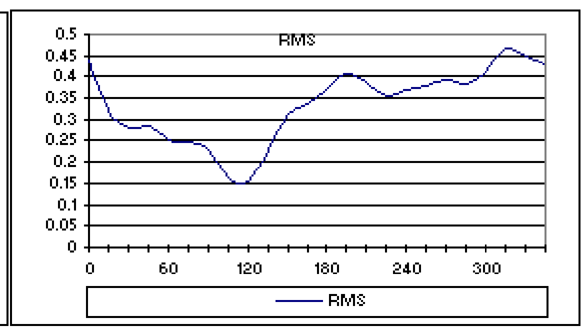
Tap #00L01 Chan #5



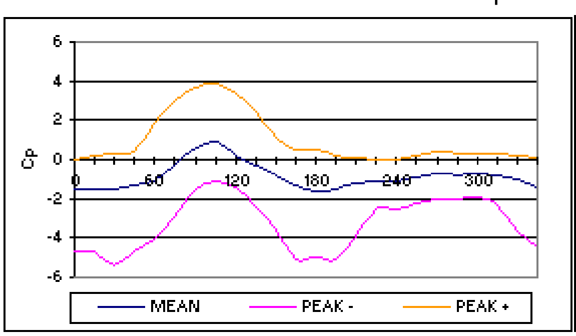


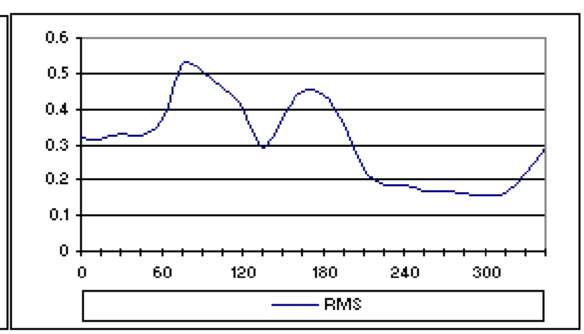
Tap #00L02 Chan #6



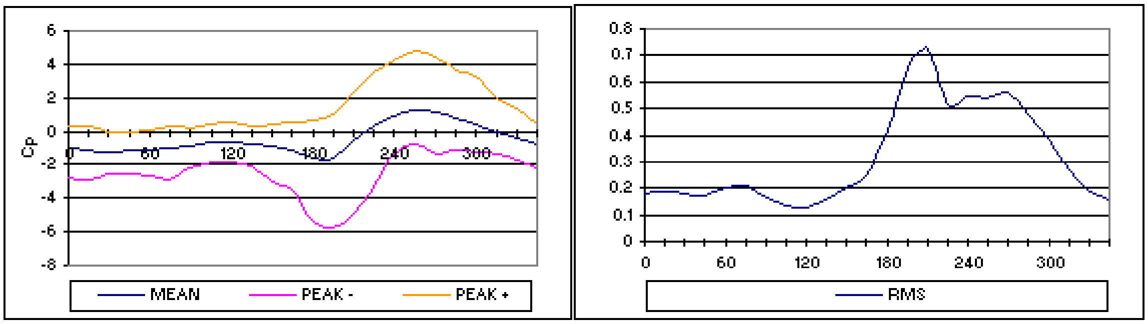


Tap #9J01 Chan #7





Tap #9L01 Chan #8



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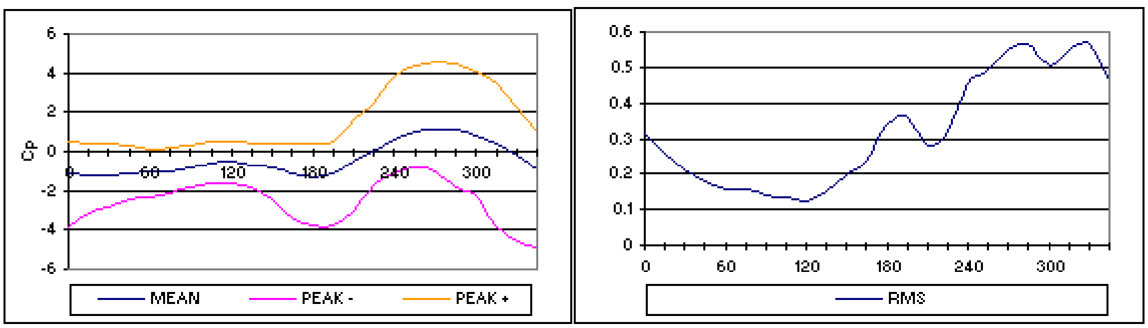
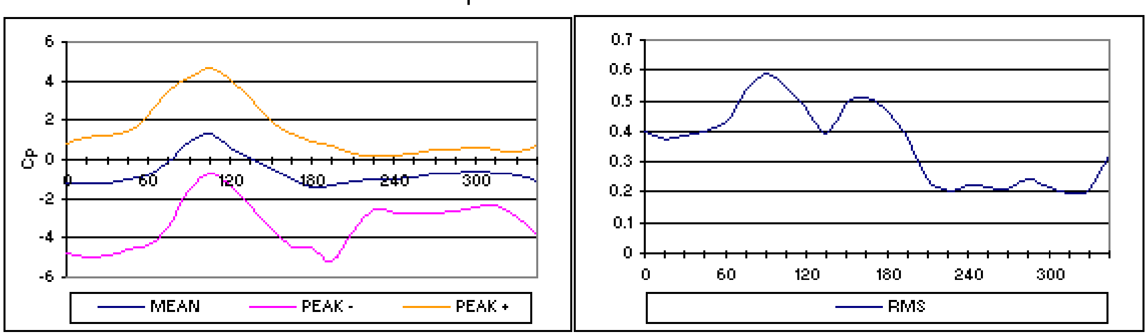


Tap #10J01 A Chan #10



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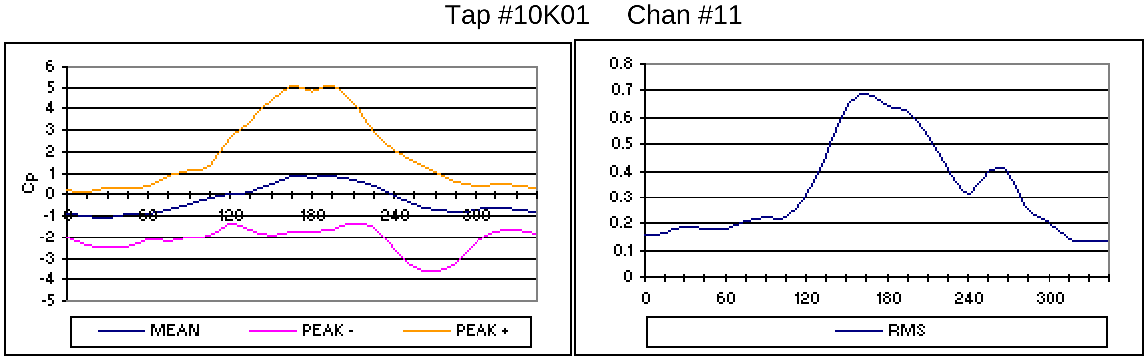
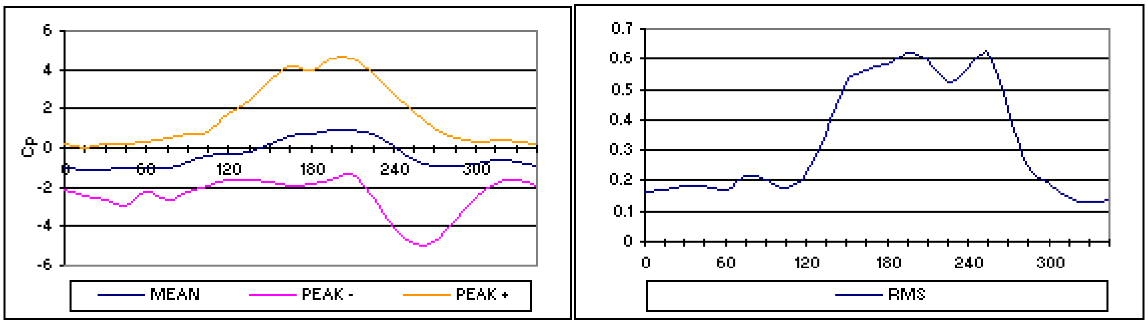
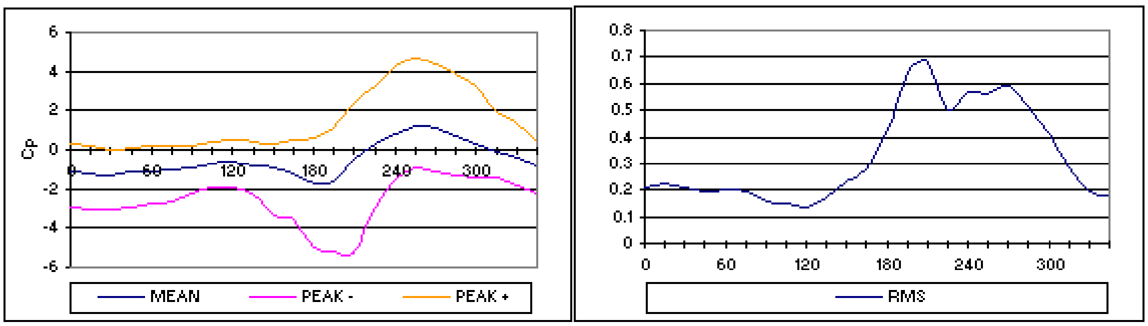


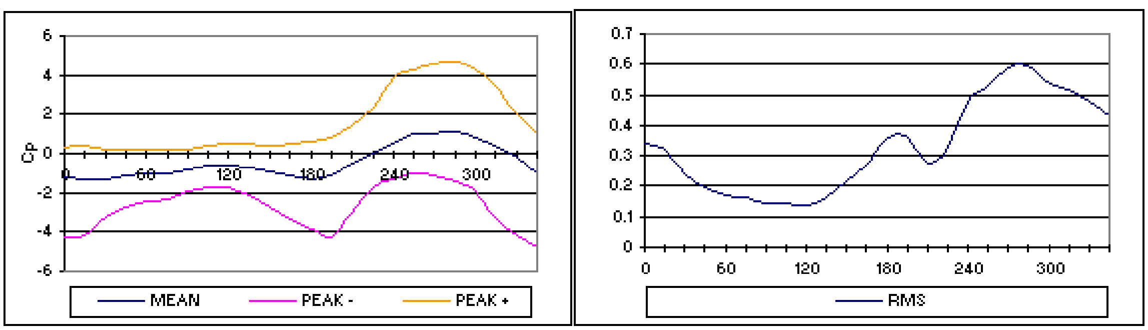
Tap #10K02 Chan #12



Tap #10L01 Chan #13



Tap #10L02 Chan #14



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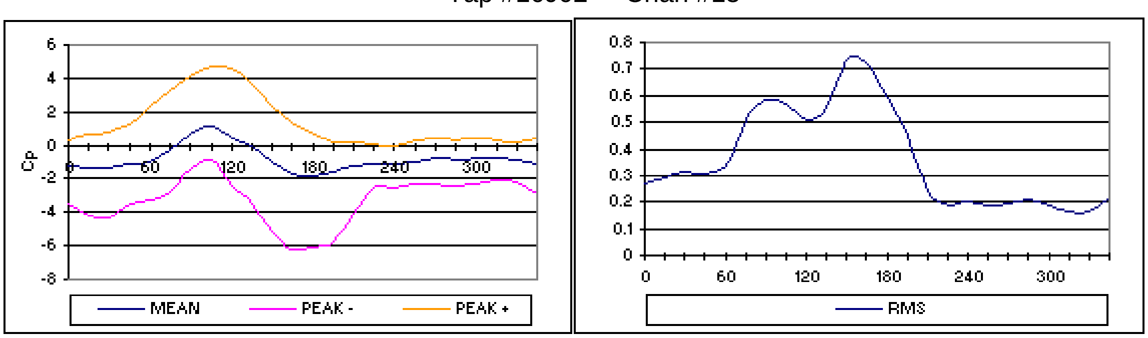
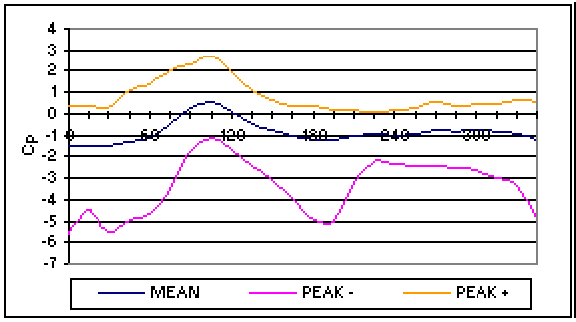
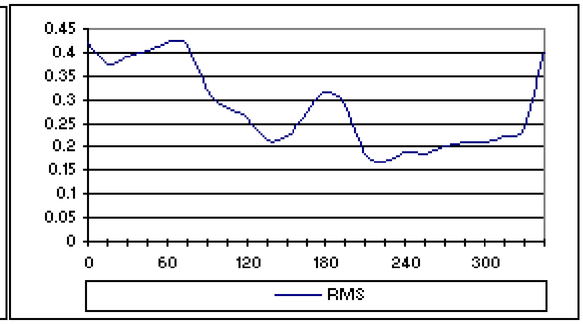


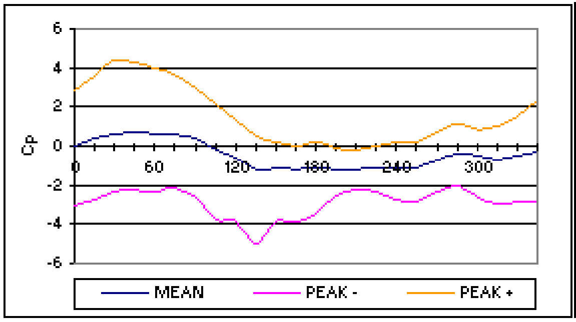
Tap #0A01 Chan #16

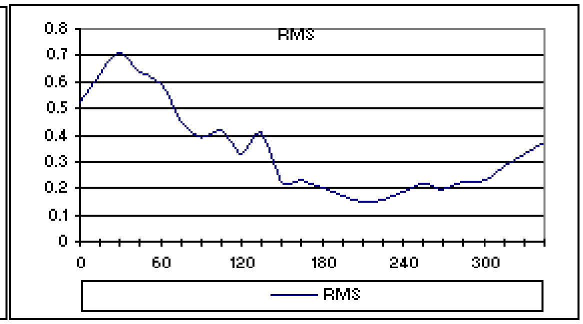




Port 4

Tap #8A14 Chan #4





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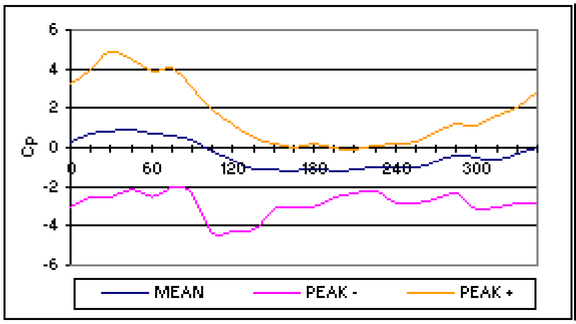
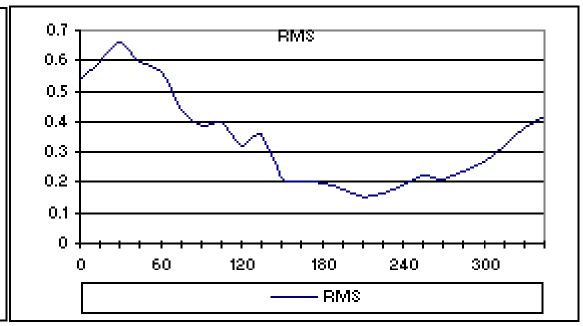
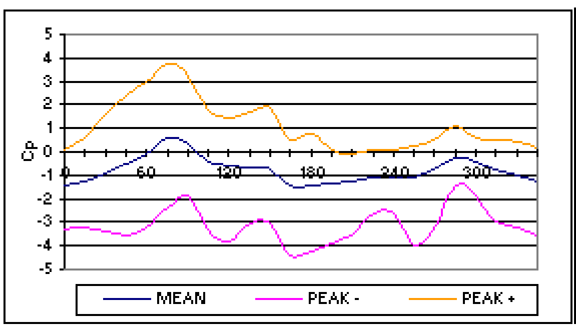
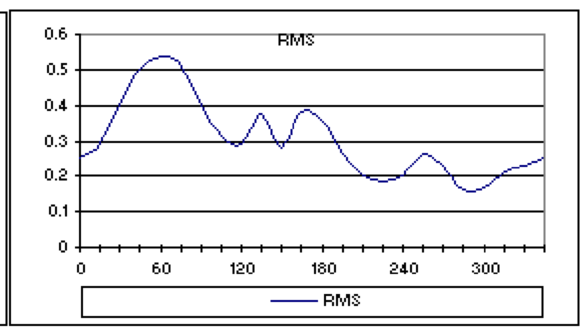


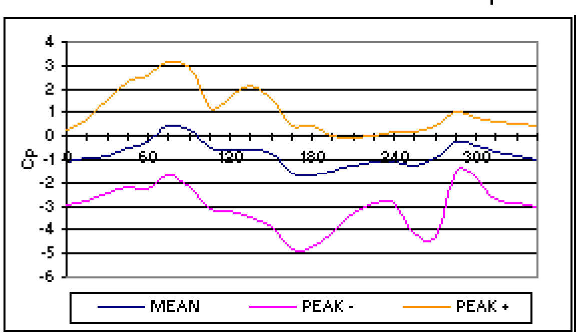


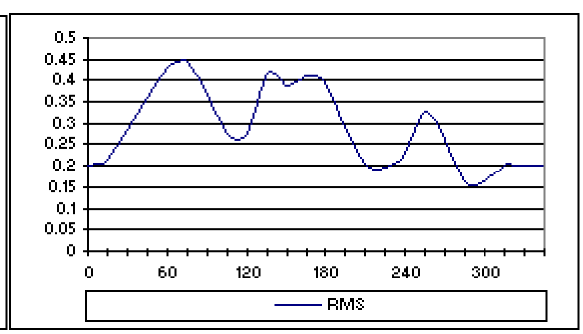
Tap #8B01 Chan #6



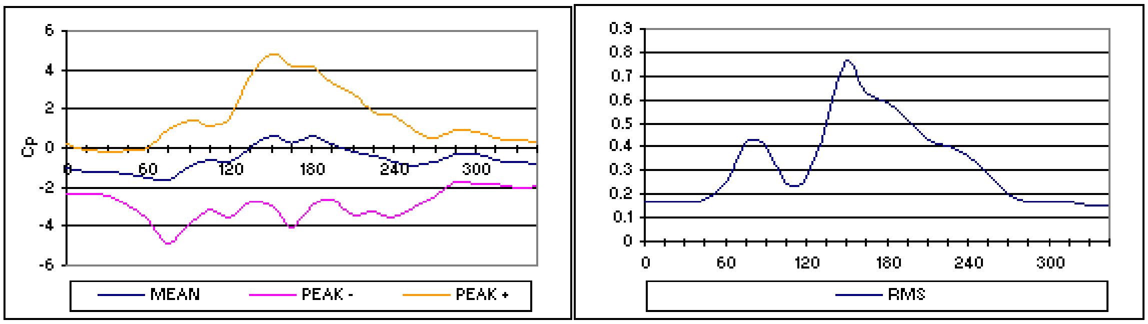


Tap #8B02 Chan #7

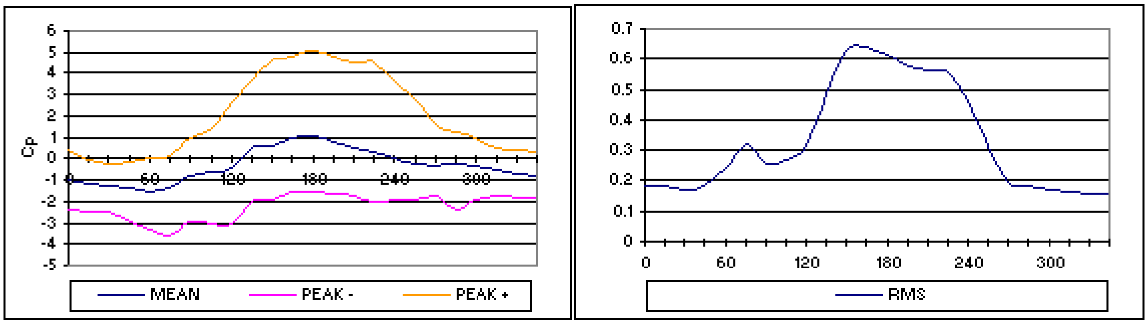




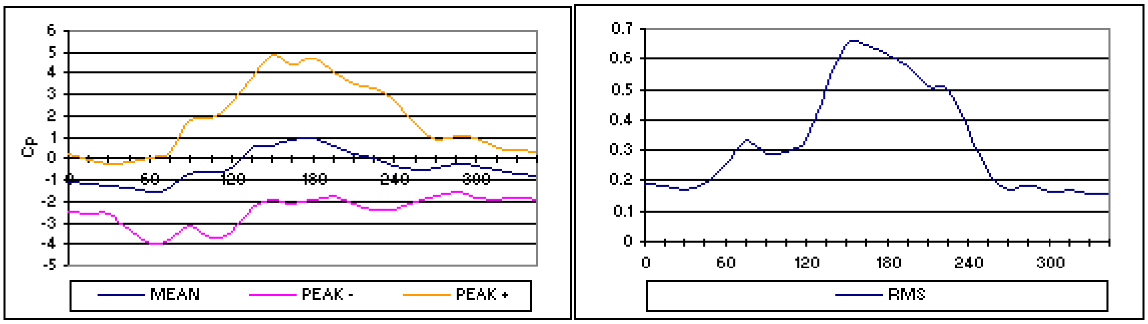
Tap #8C01 Chan #8



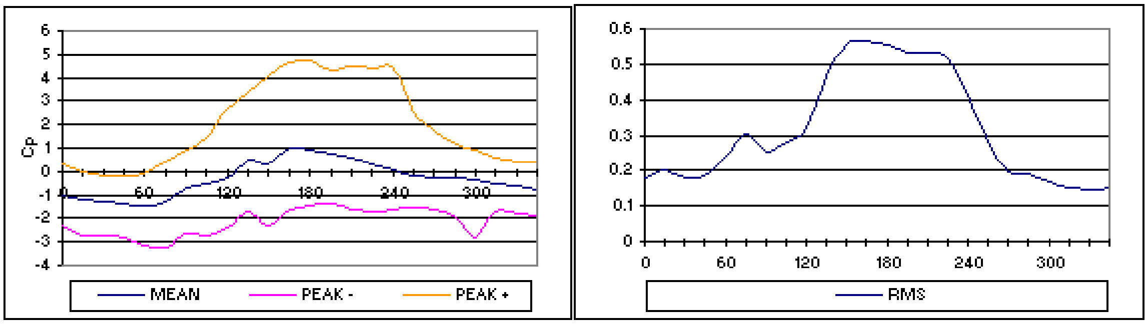
Tap #8C02 Chan #9



Tap #8C03 Chan #10



Tap #8C04 Chan #11



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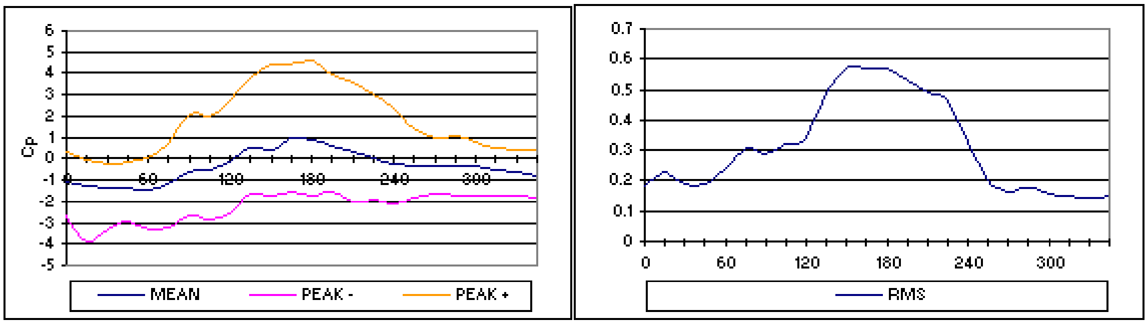

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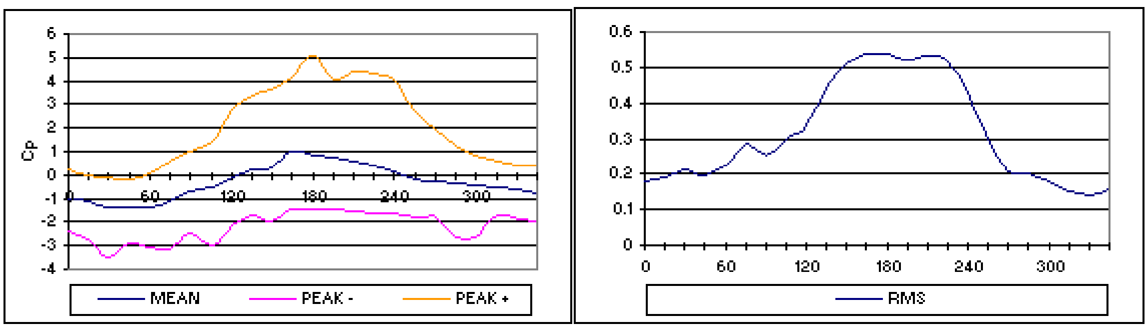

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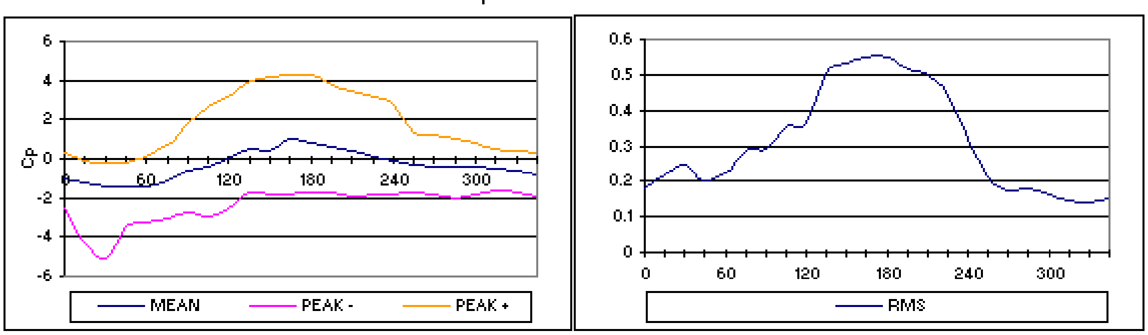

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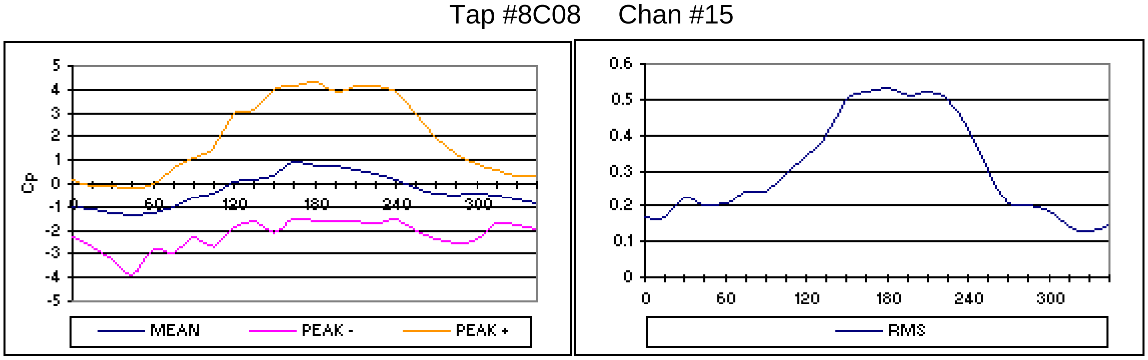
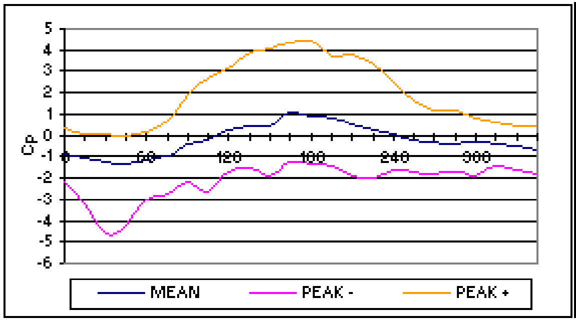
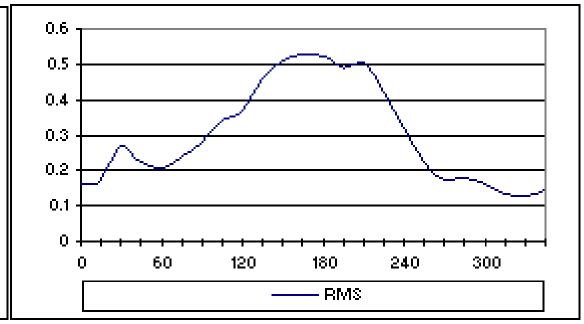


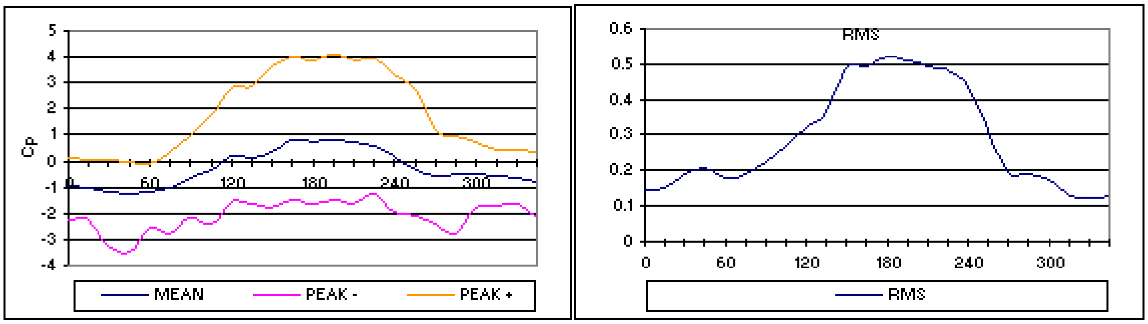
Tap #8C09 Chan #16



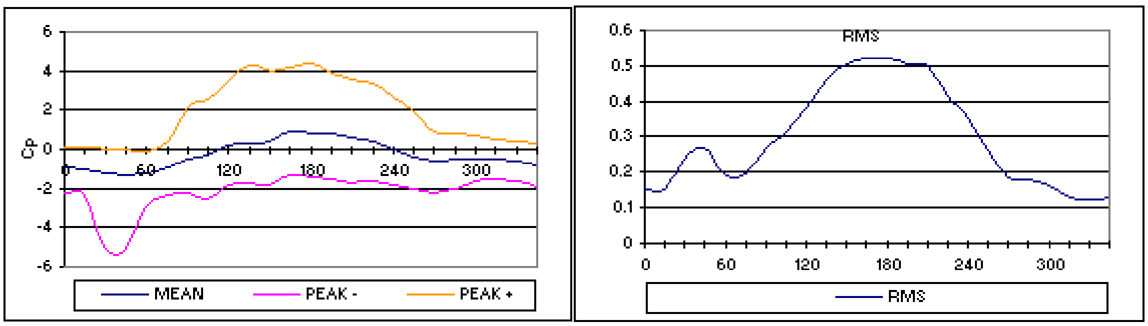


Port 5

Tap #8C10 Chan #4



Tap #8C11 Chan #5



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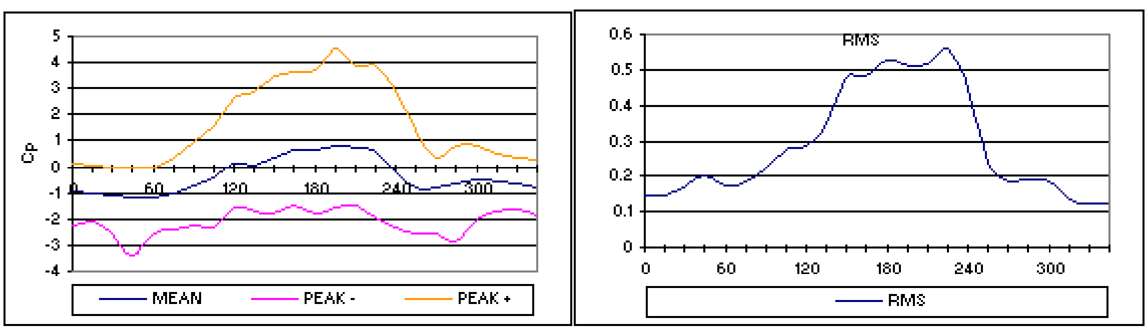

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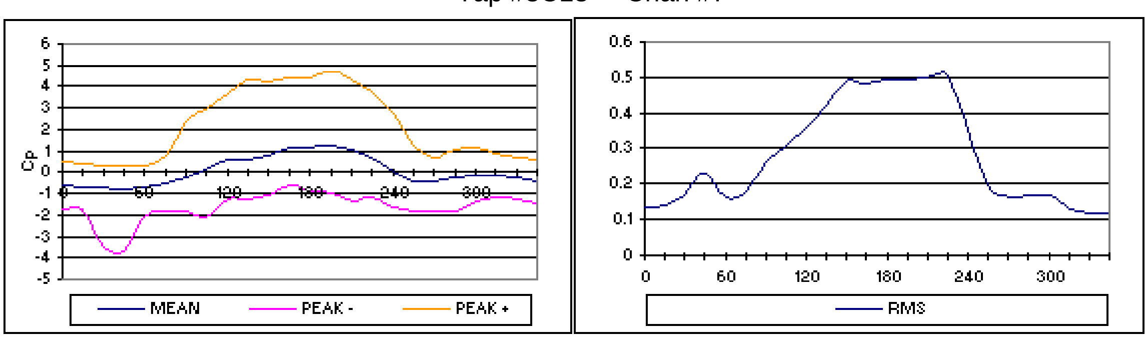

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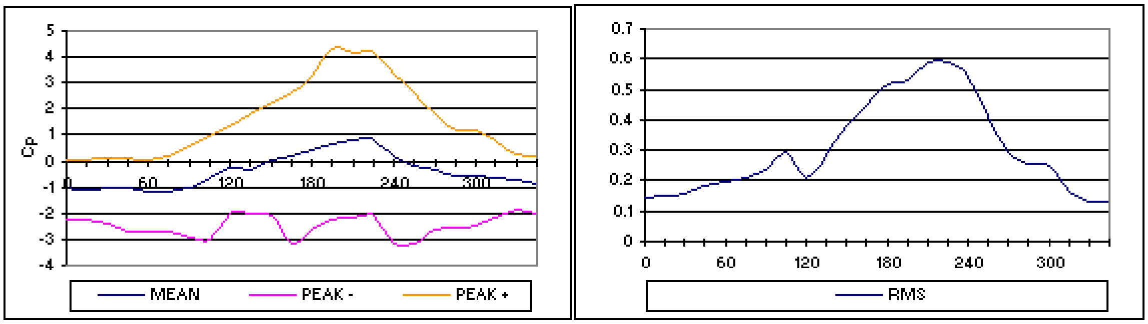

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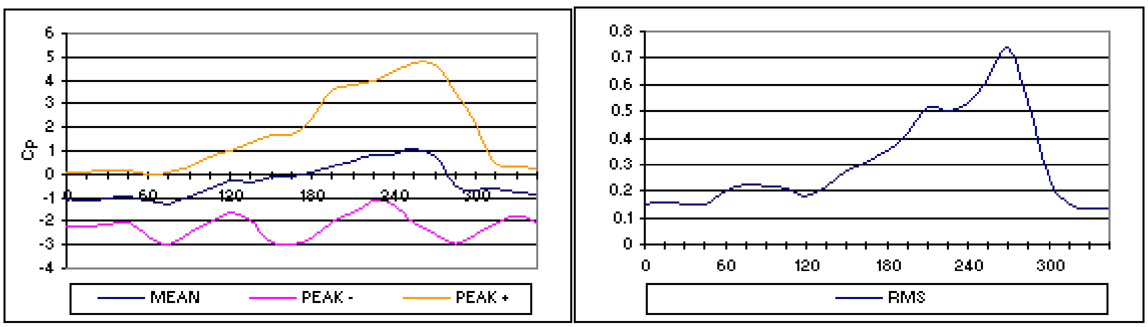

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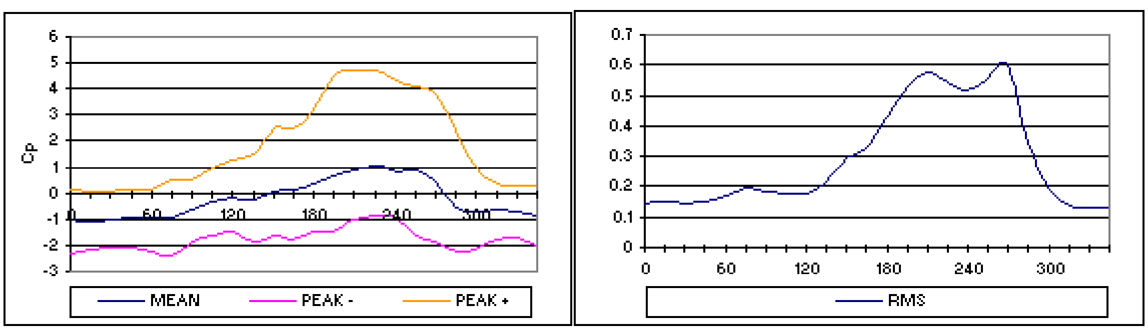

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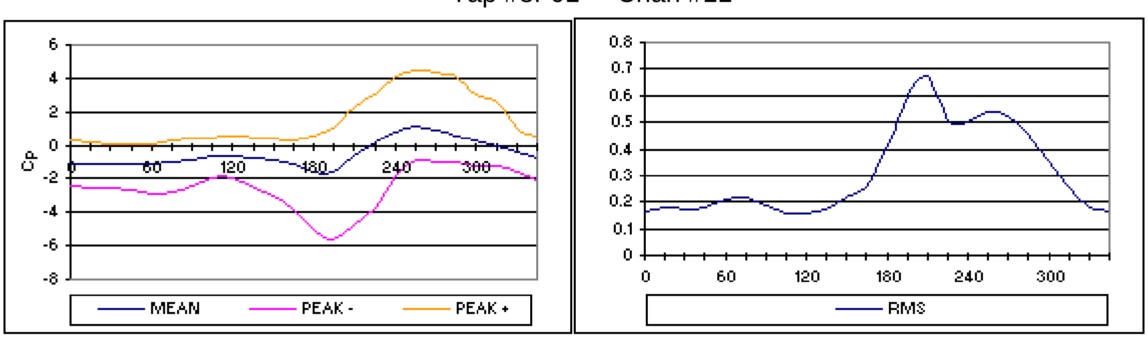
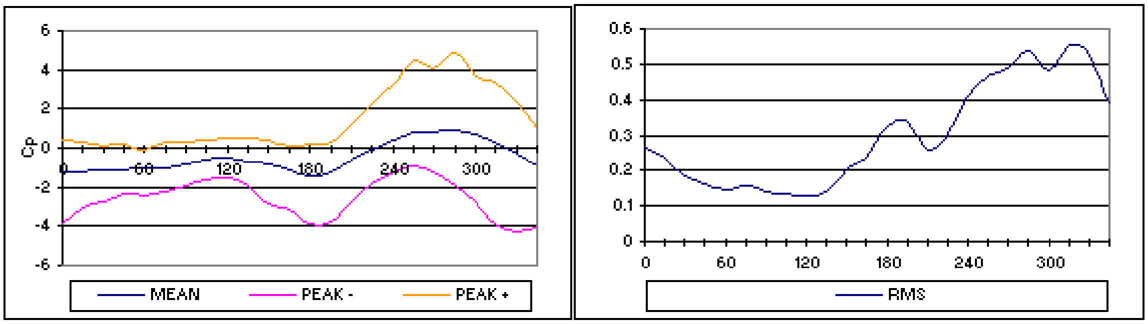


Tap #8F02   Chan #12



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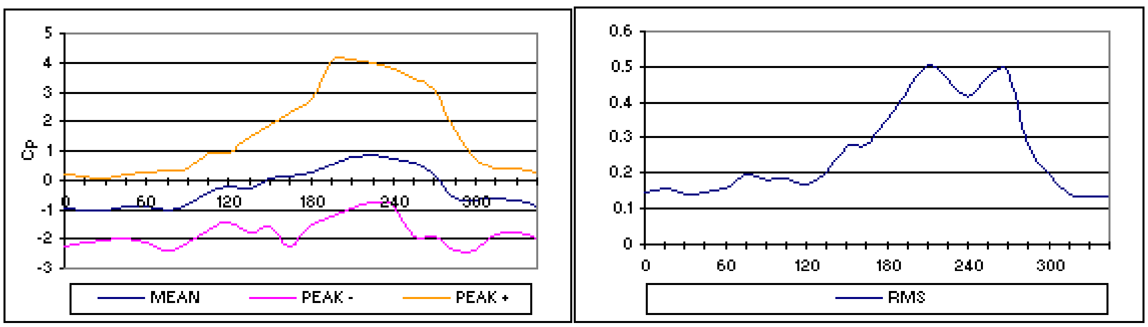

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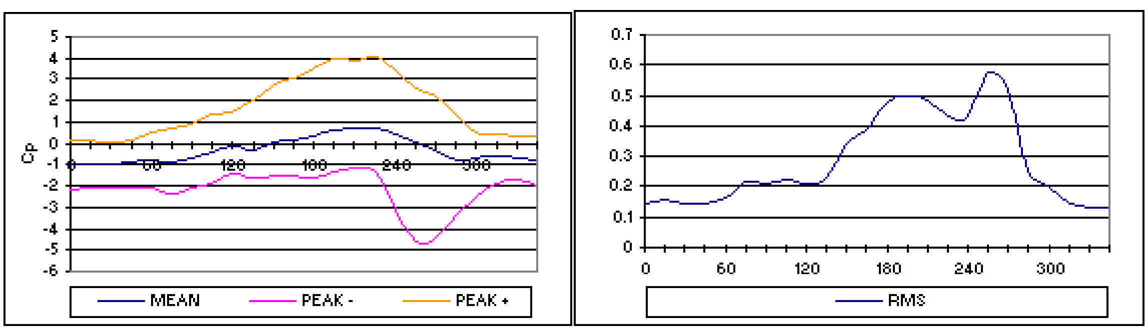

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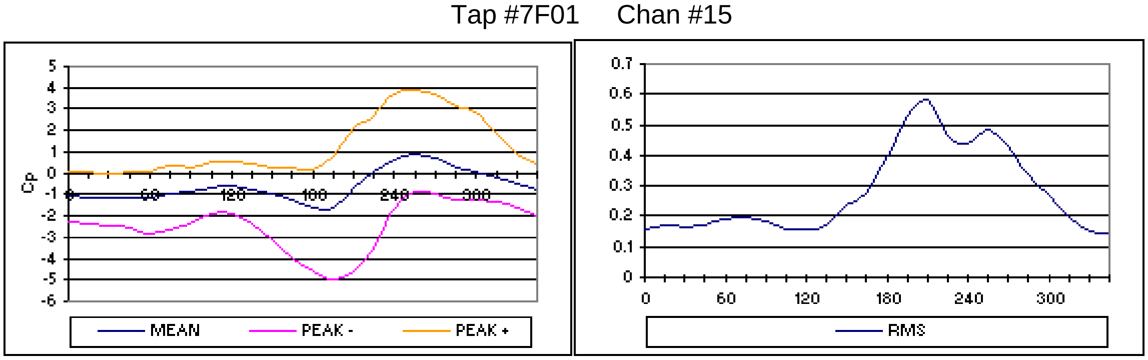
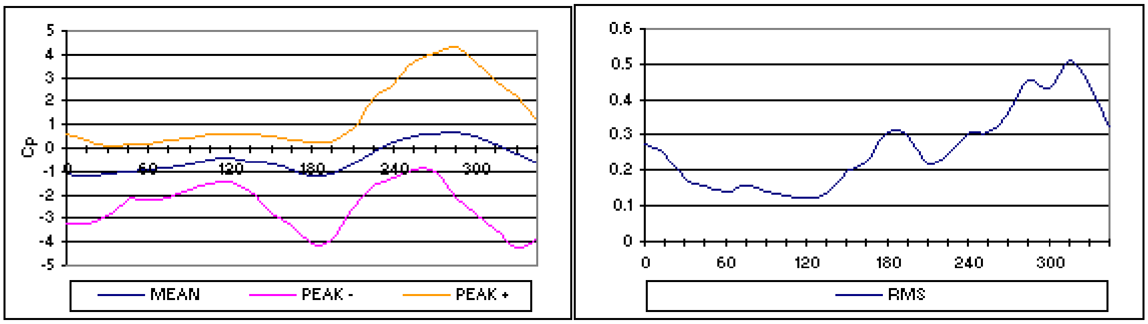
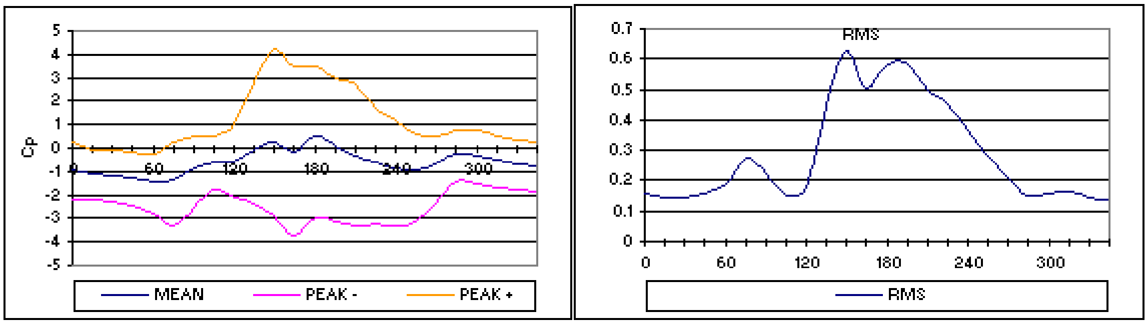


Tap #7F02   Chan #16

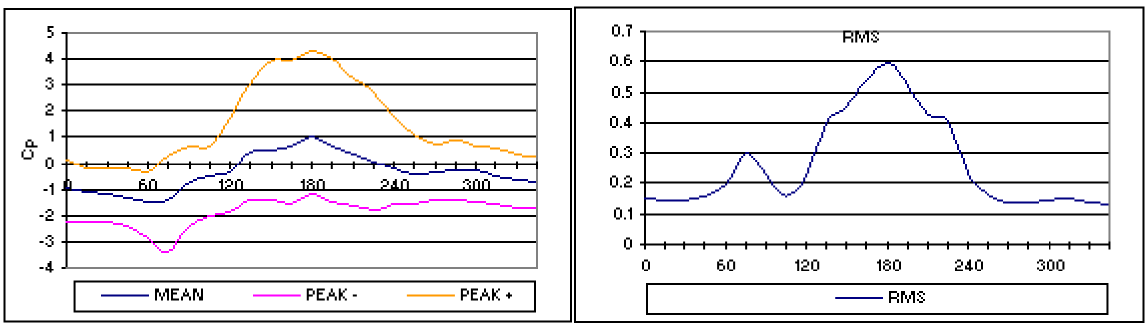


Port 6

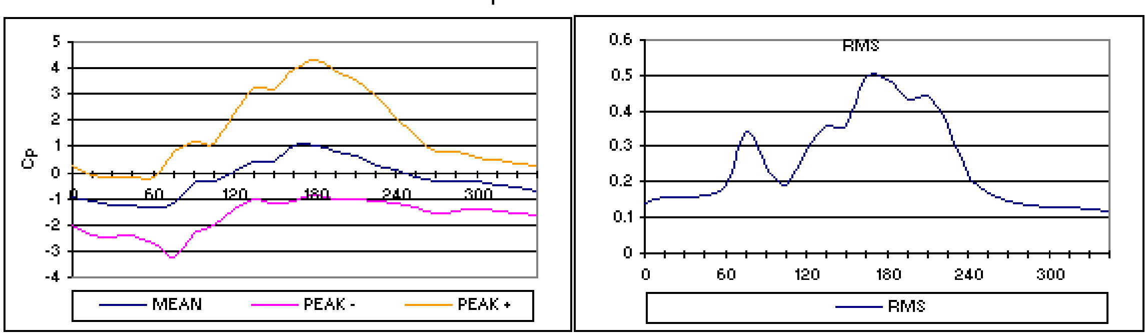
Tap #6C01 Chan #4



Tap #6C02 Chan #5



Tap #6C03 Chan #6



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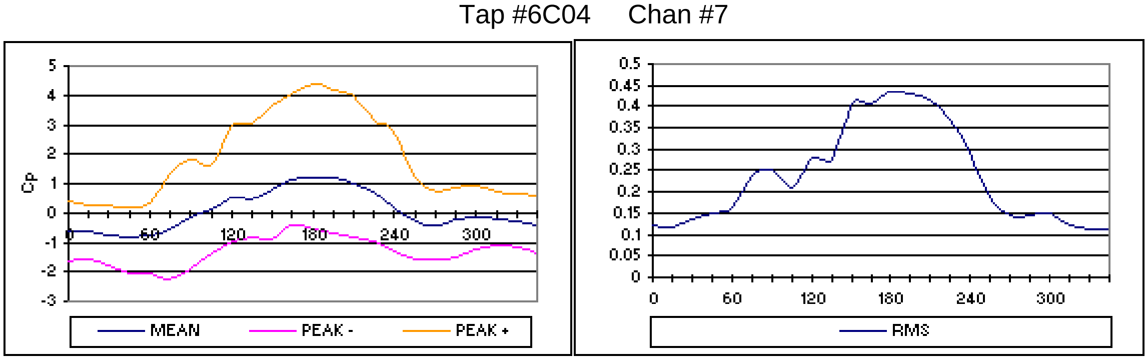

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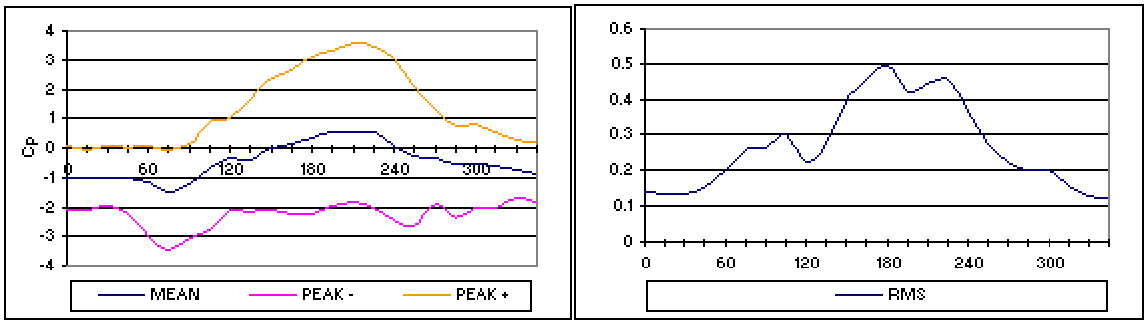

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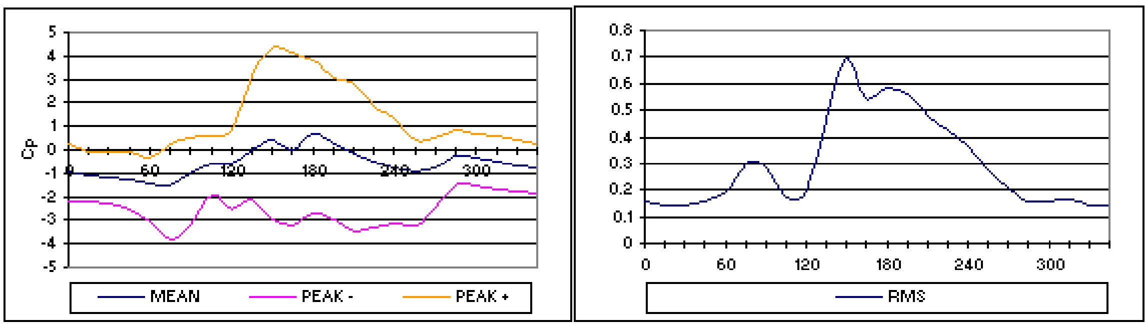

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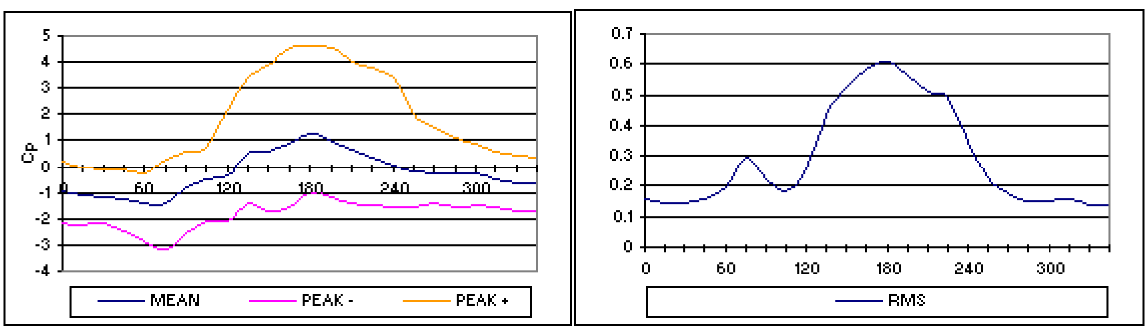

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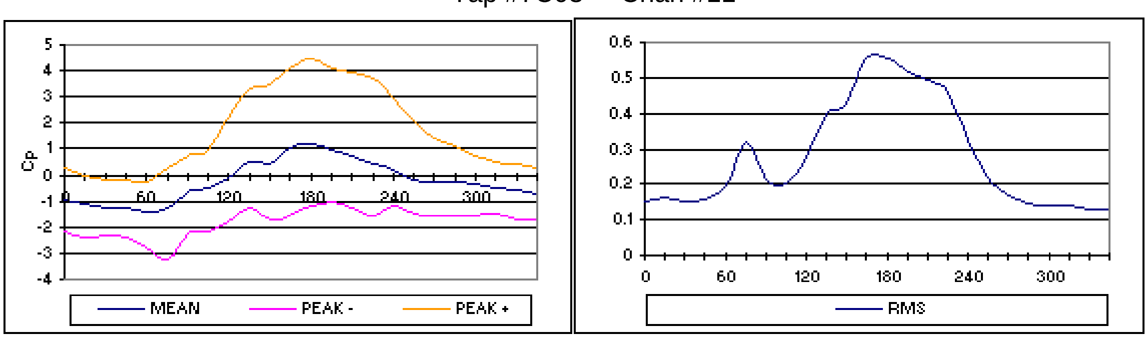

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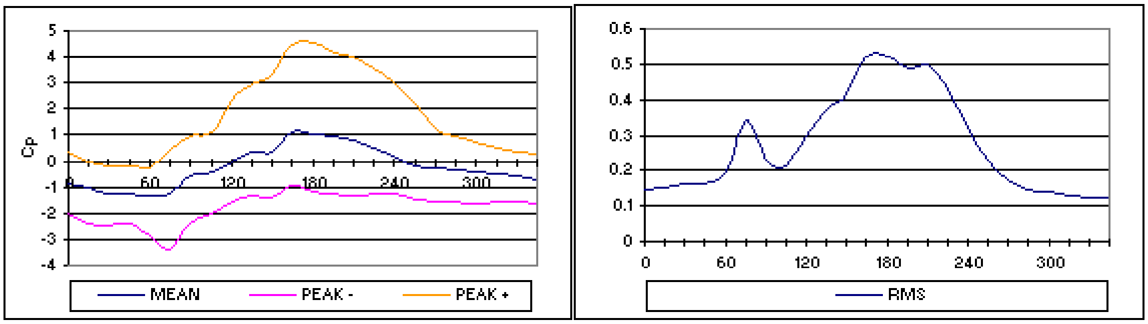

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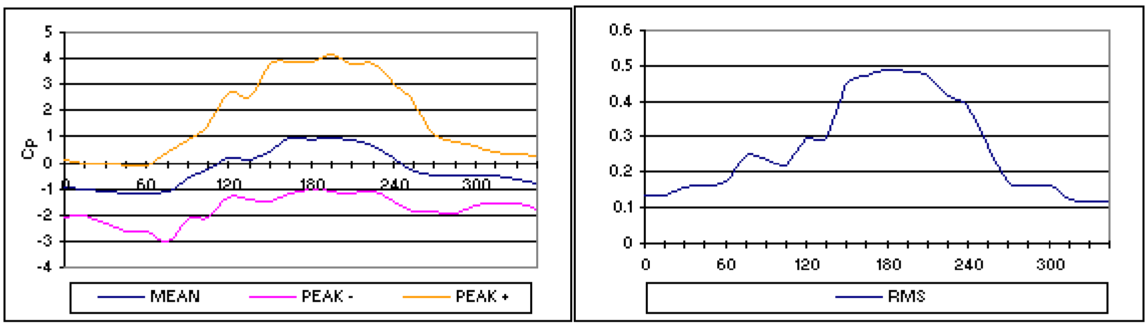

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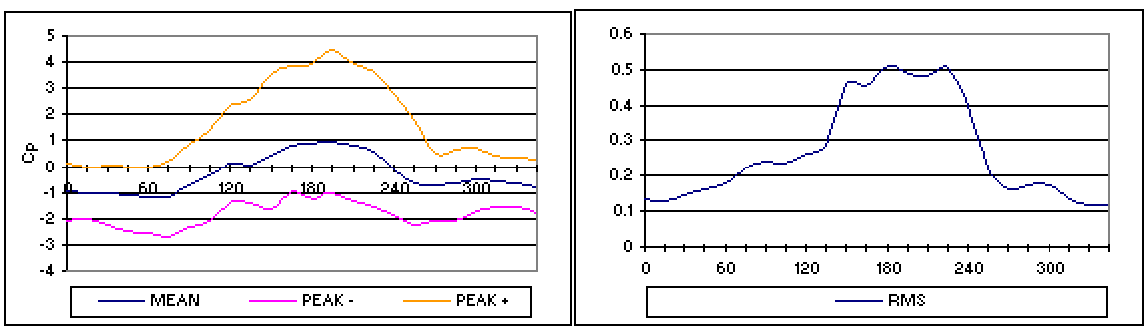
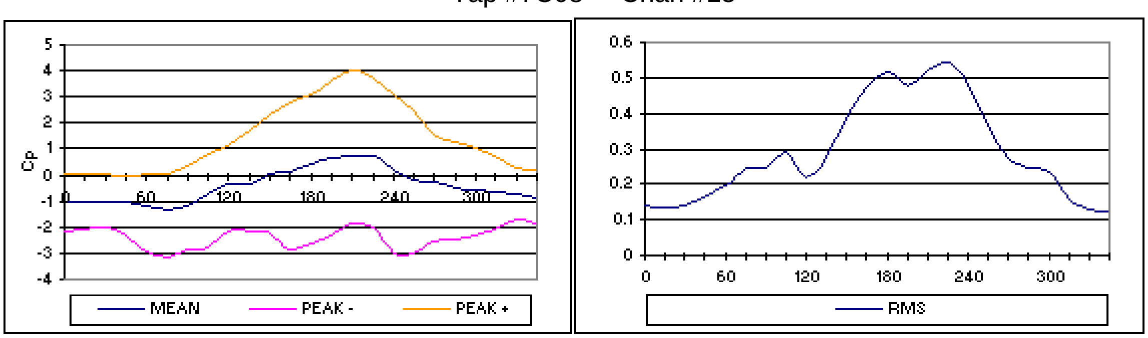


Tap #7C08 Chan #15



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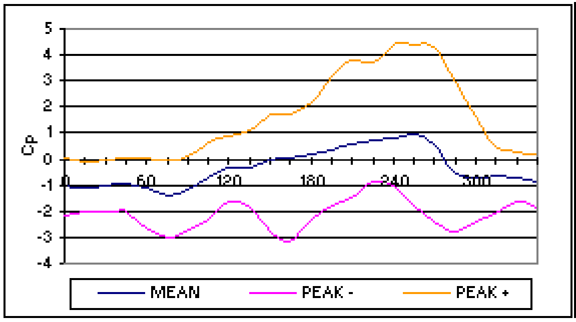
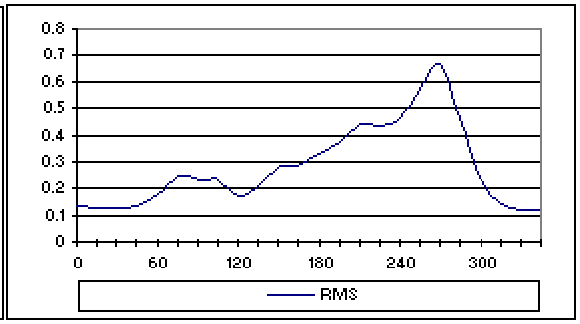
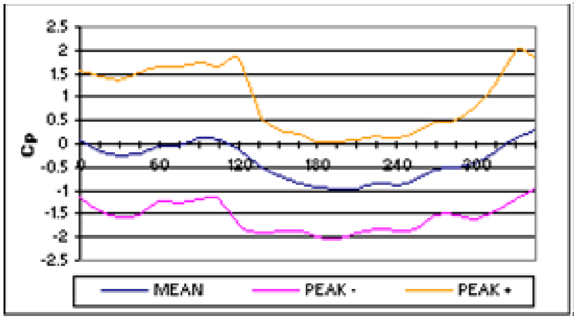
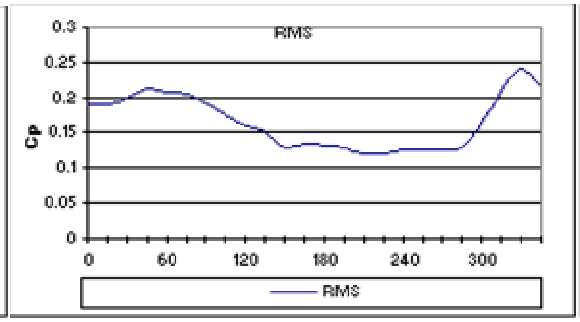




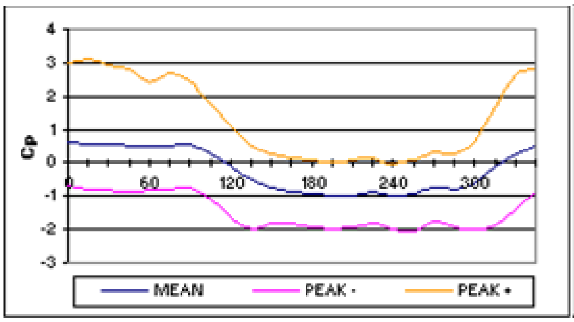
Port 7

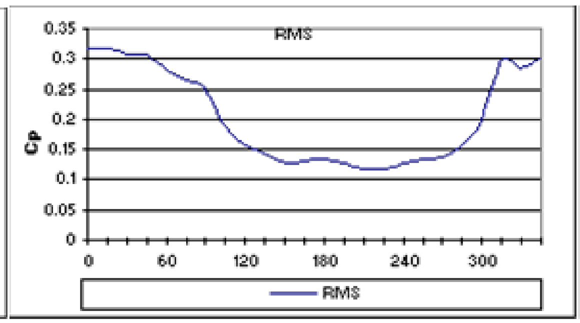
Tap #6A01 Chan #4



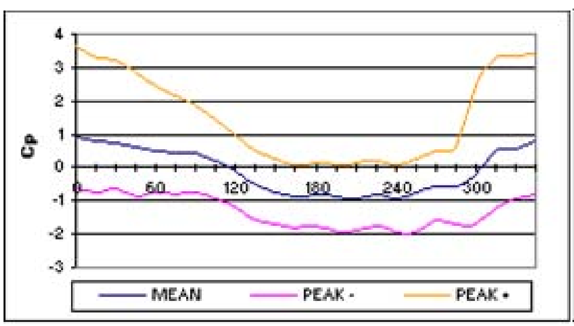


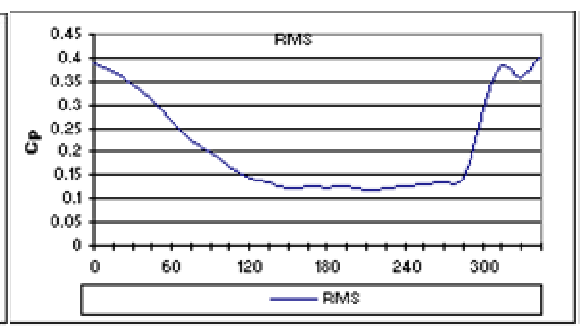
Tap #6A02 Chan #5



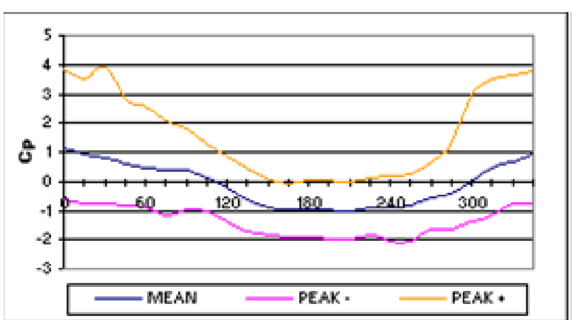


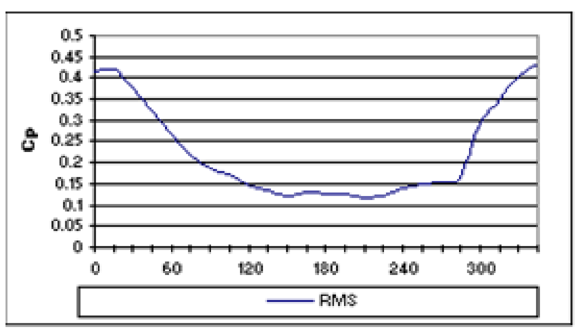
Tap #6A03 Chan #6





Tap #6A04 Chan #7





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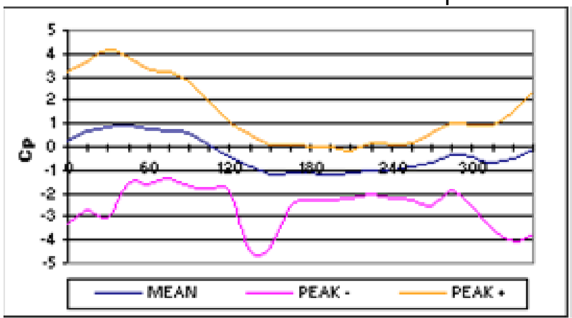

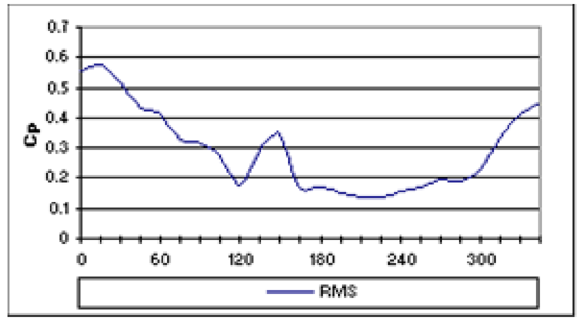

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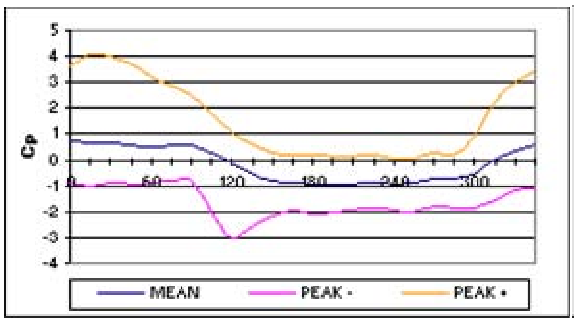

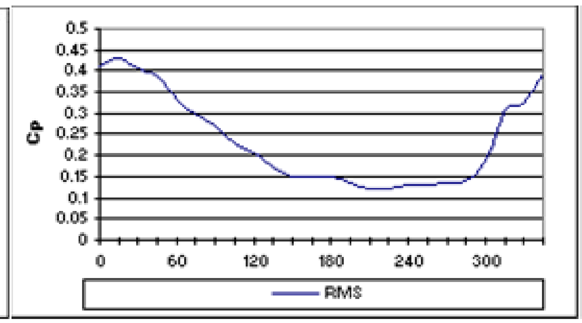

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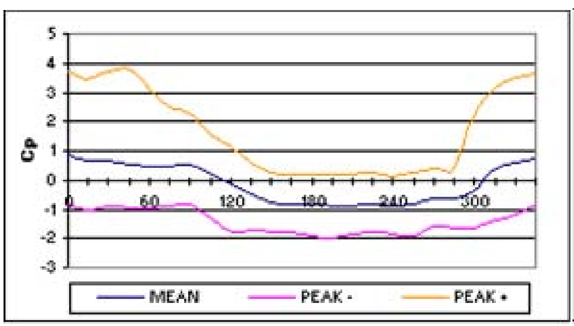

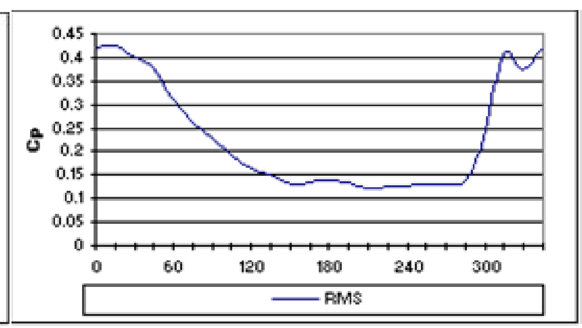

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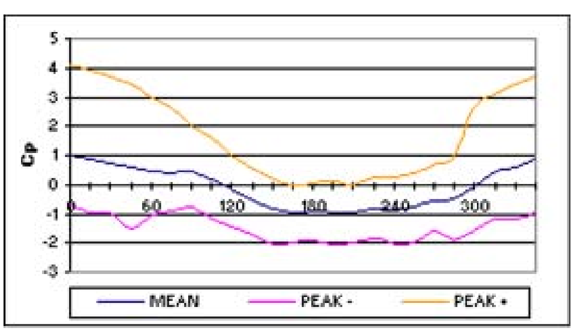

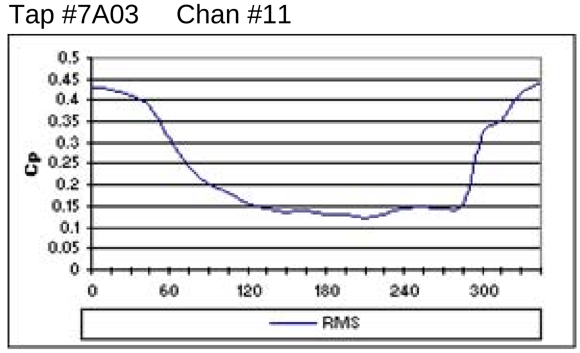

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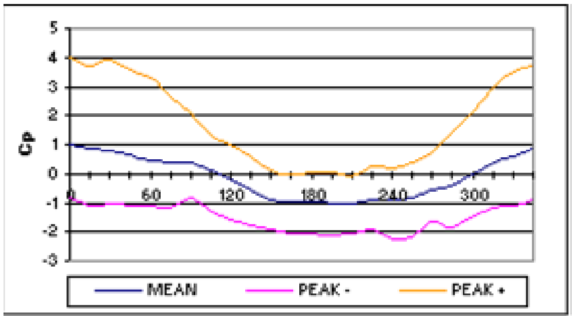

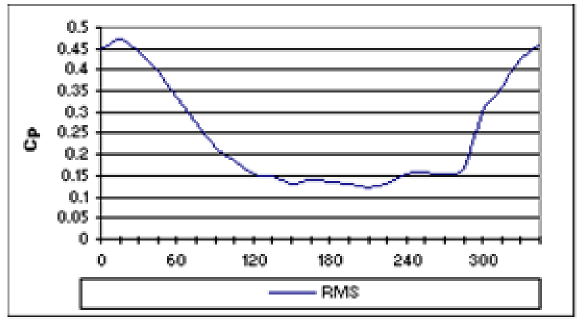

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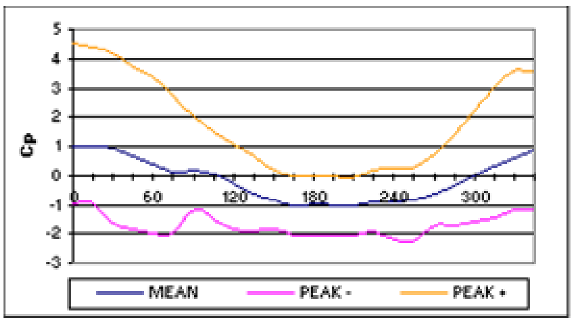

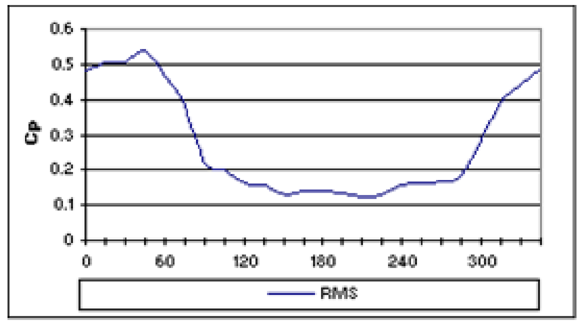

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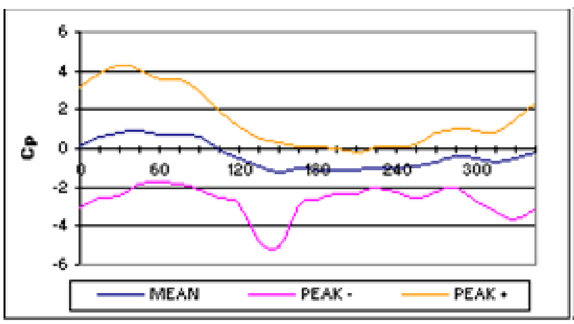

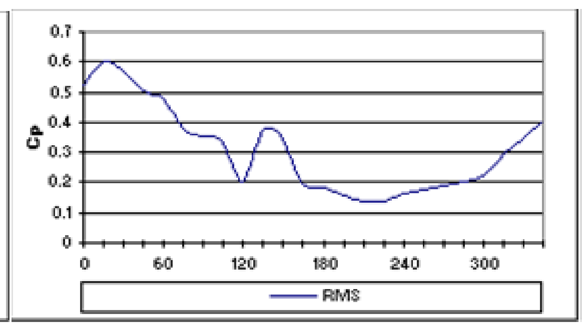

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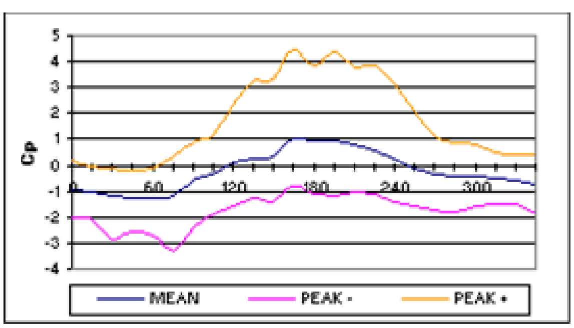
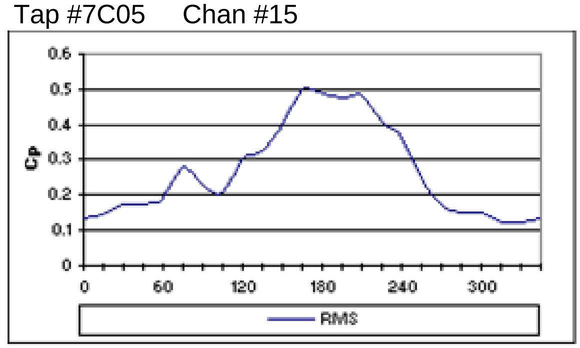
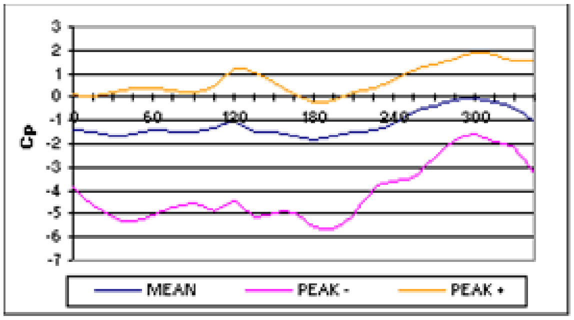
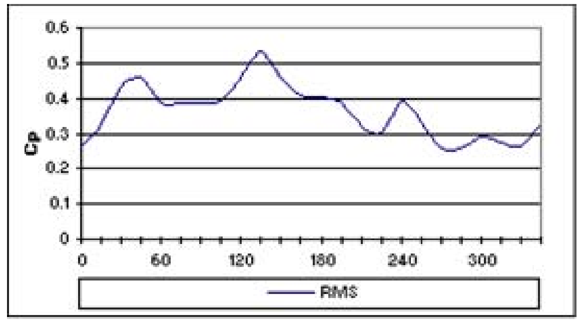




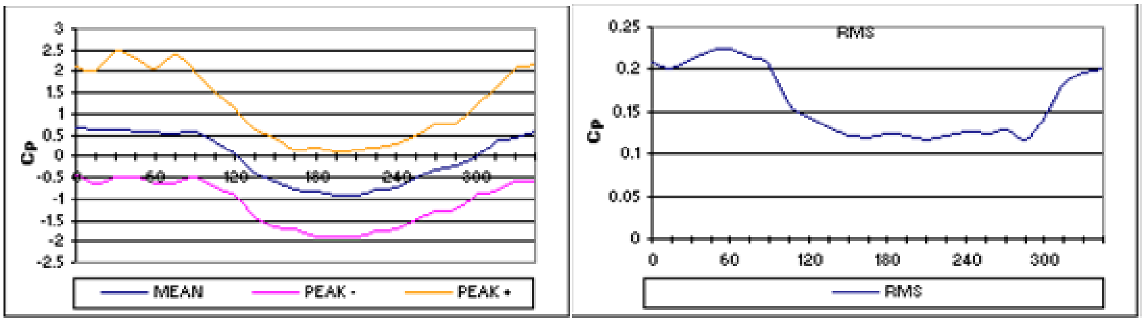
Tap #00J01   Chan #16



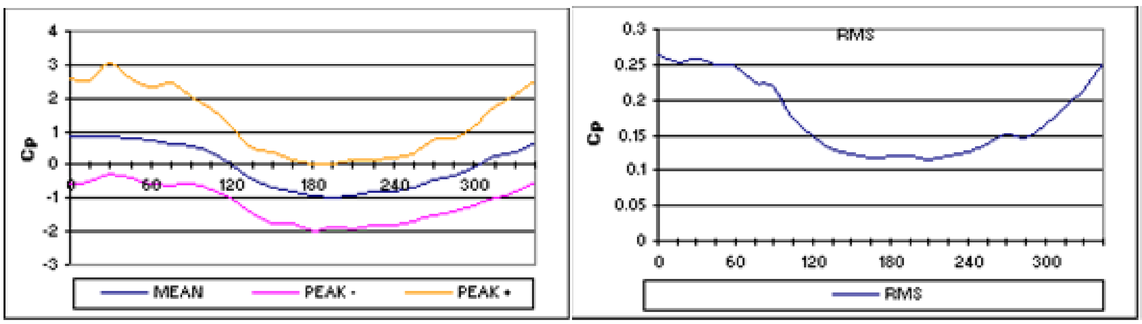


Port 8

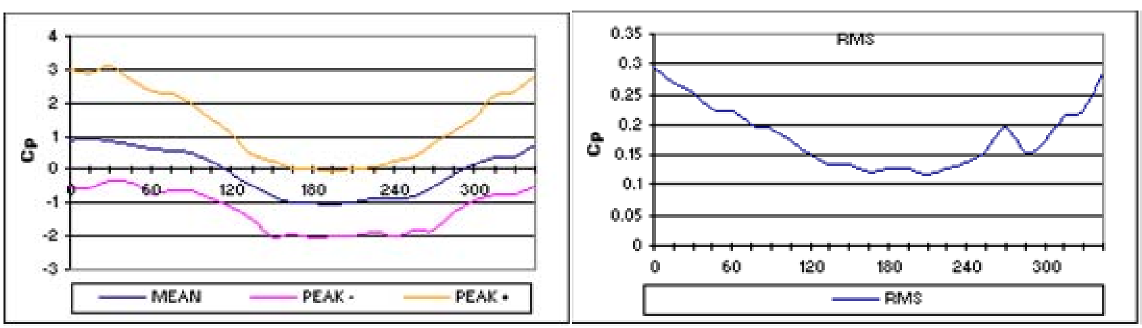
Tap #1A01 Chan #4



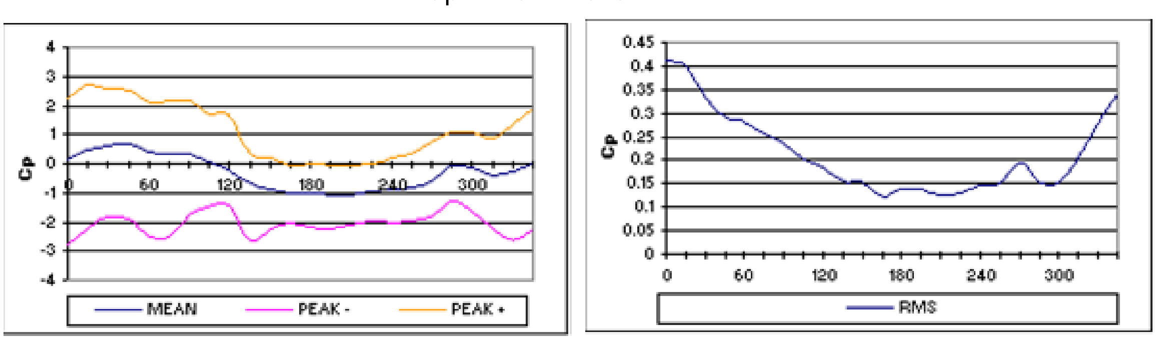
Tap #1A02 Chan #5



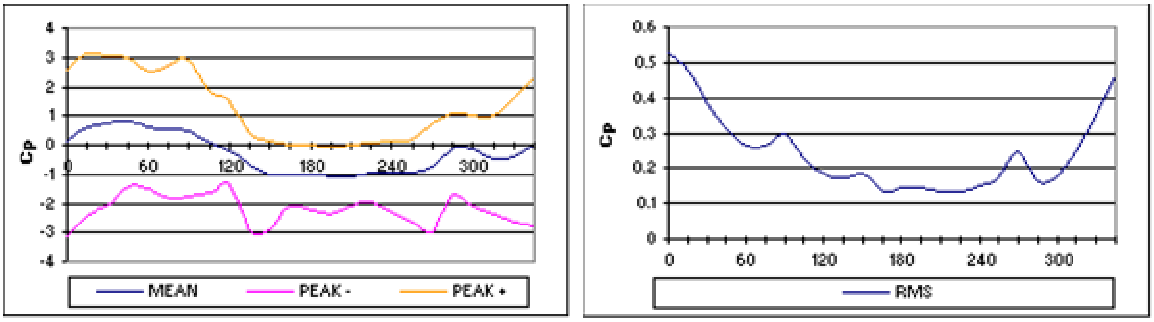
Tap #1A03 Chan #6



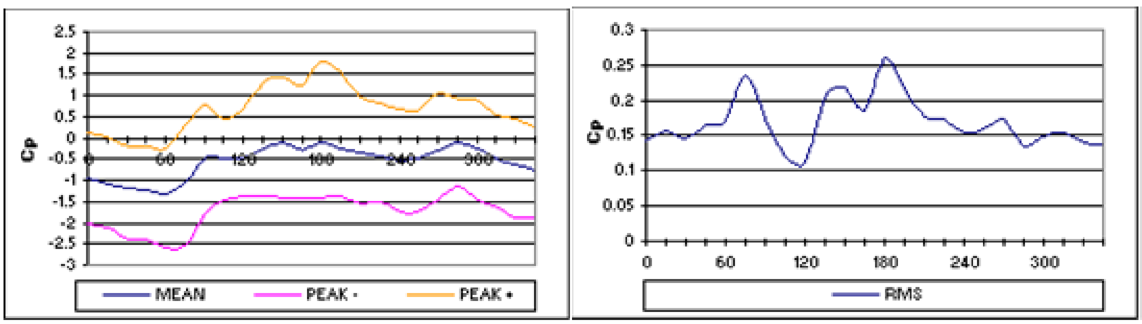
Tap #1A04 Chan #7



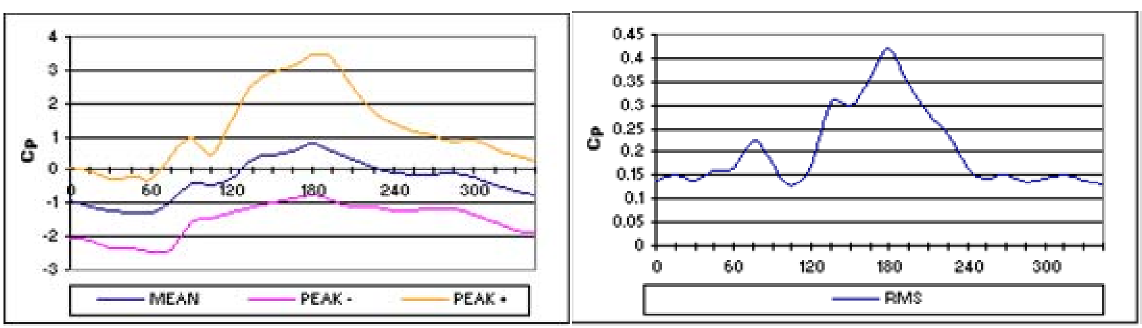
Tap #2A01 Chan #8



Tap #2C01 Chan #9



Tap #2C02 Chan #10



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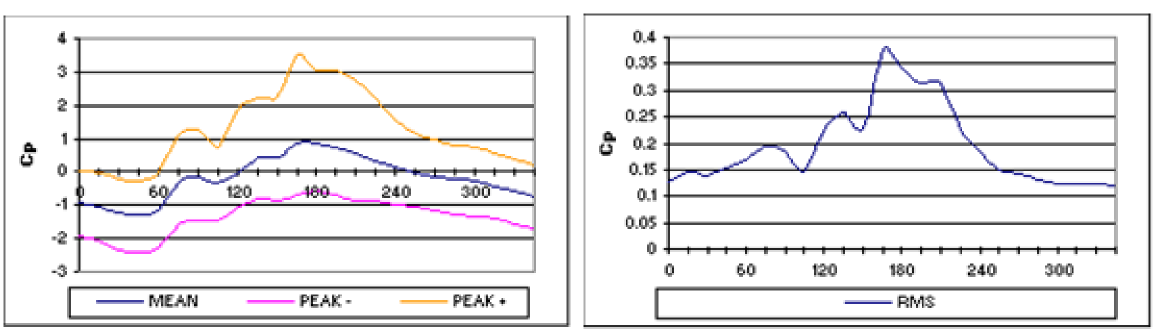

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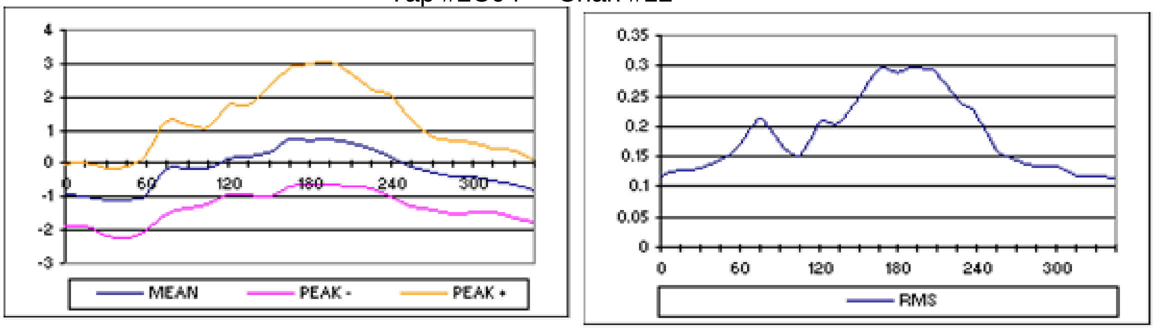

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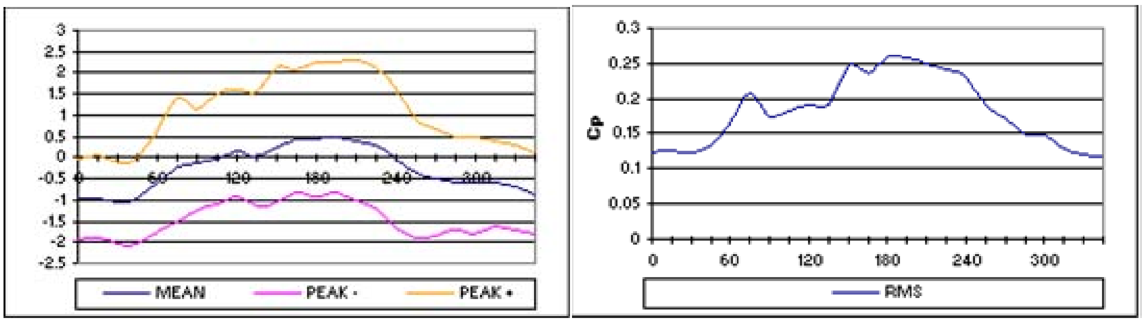
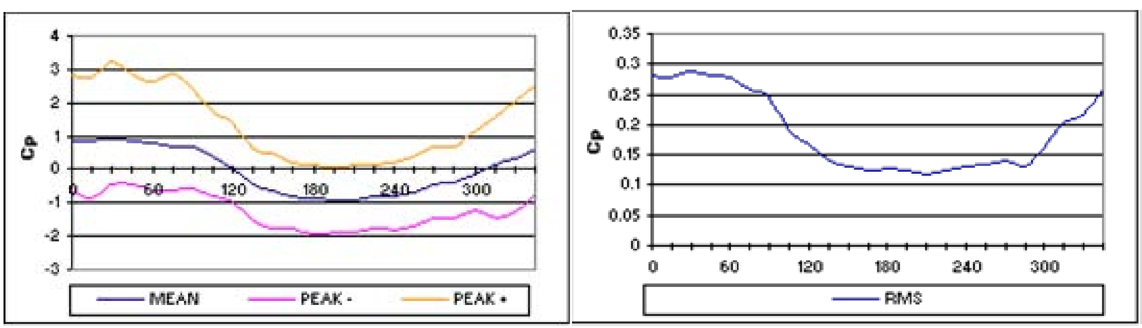
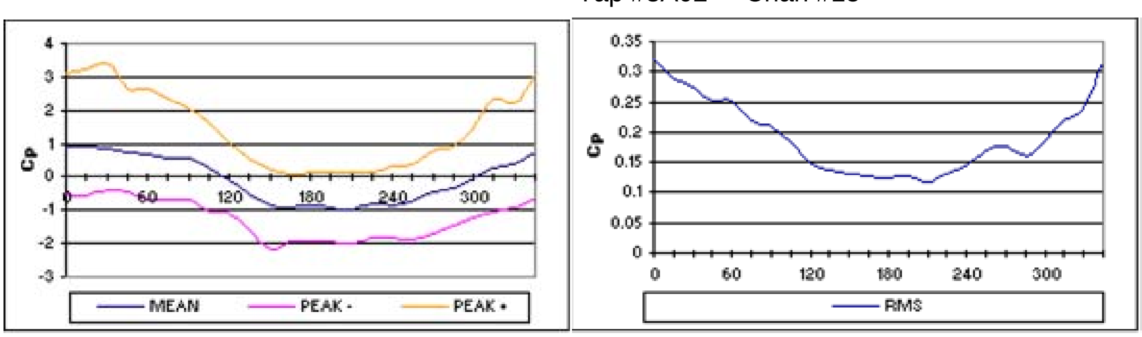


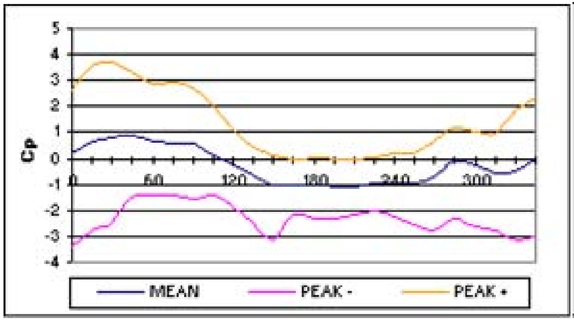
Tap #3A01 Chan #14

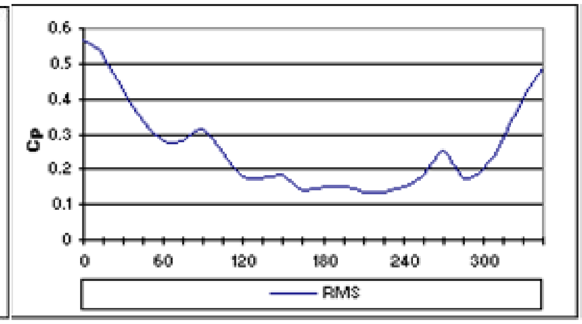


Tap #3A02 Chan #15



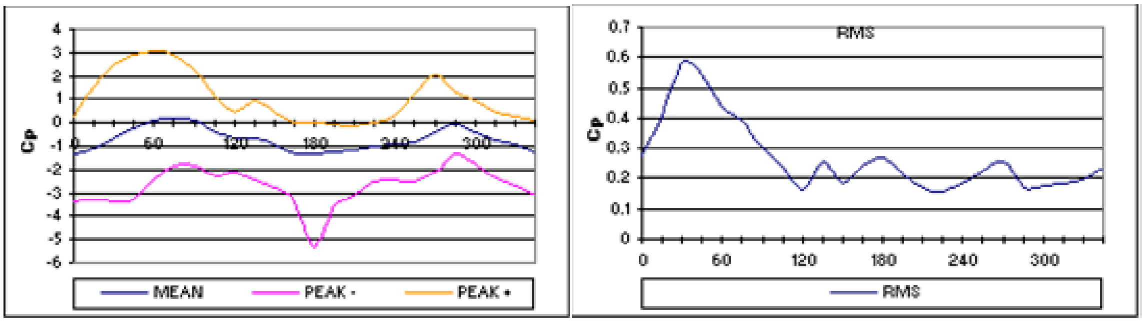
Tap #3A03   Chan #16



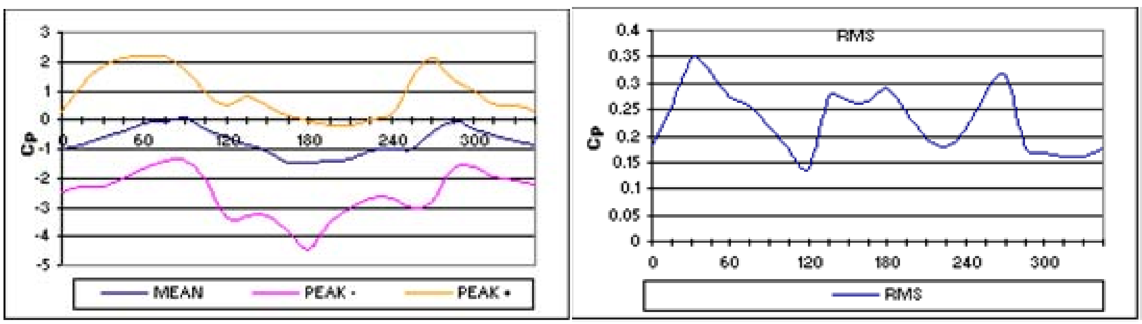


Port 9

Tap #3B01 Chan #4



Tap #3B02 Chan #5



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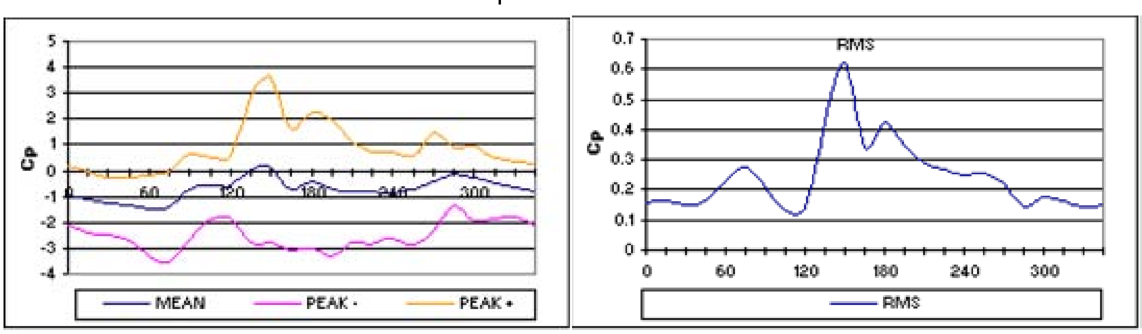

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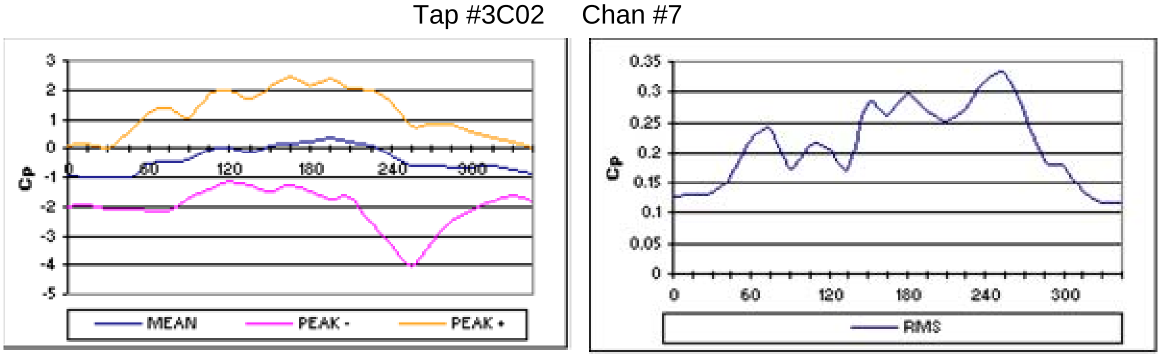

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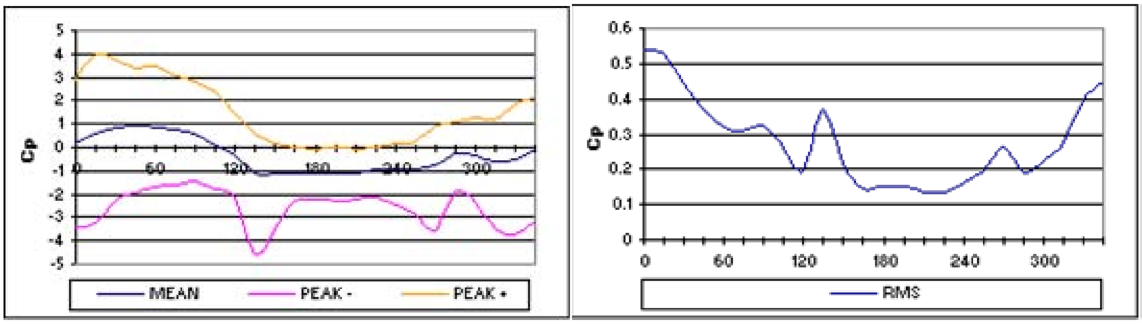

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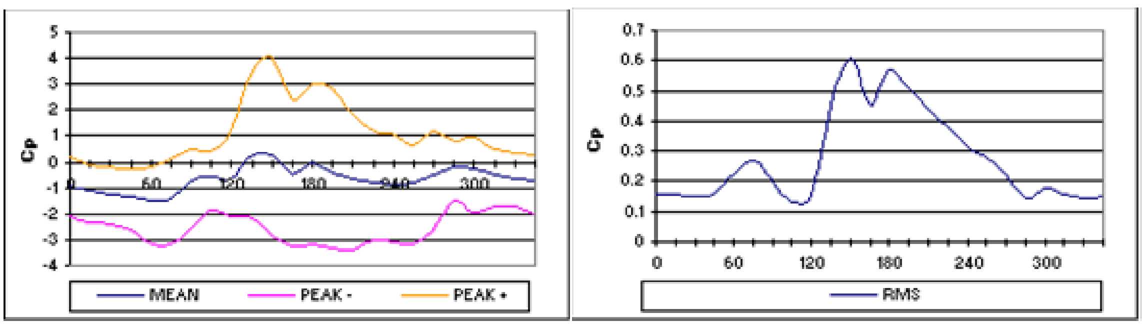

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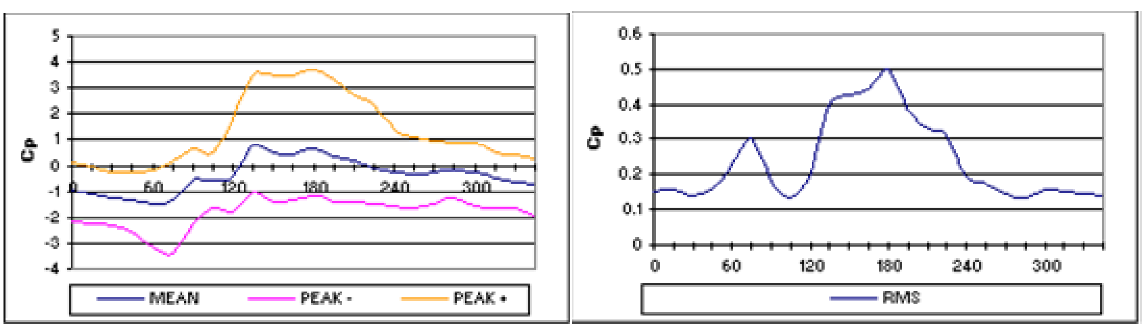
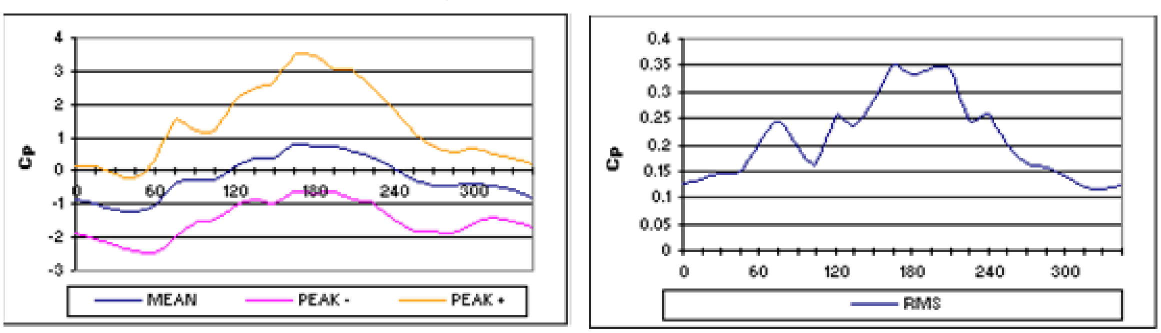


Tap #4C04 Chan #11



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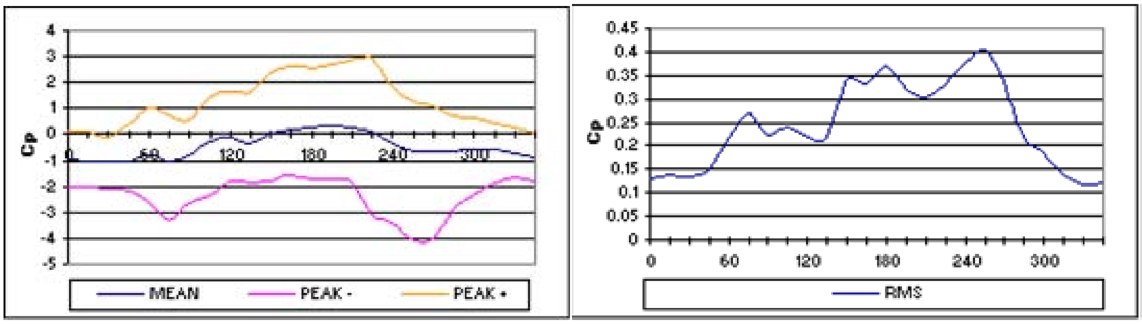
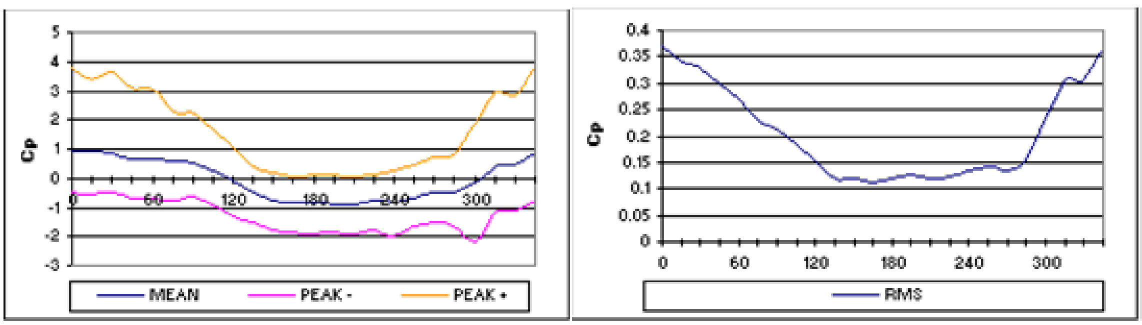


Tap #5A01 Chan #13



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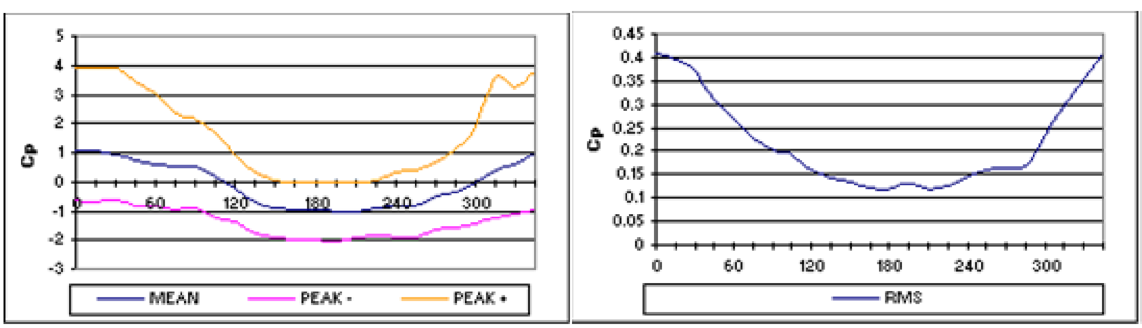
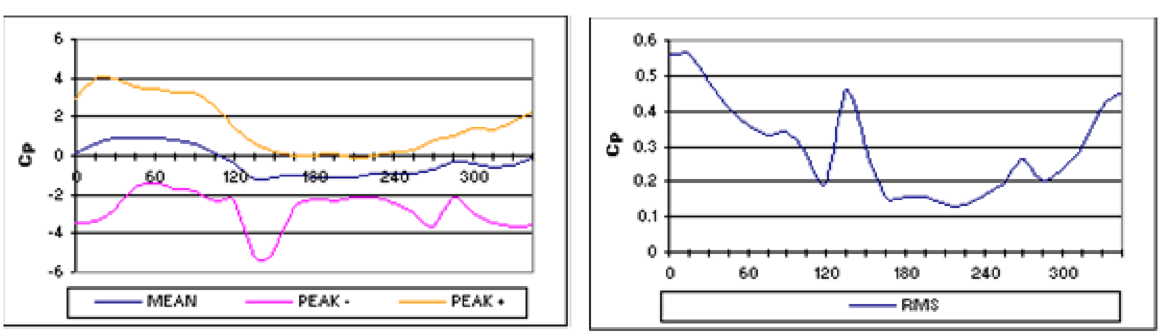


Tap #5A03 Chan #15



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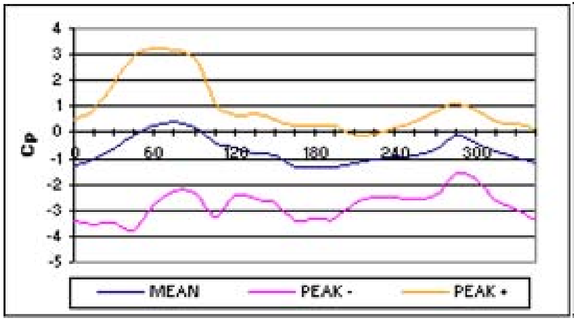

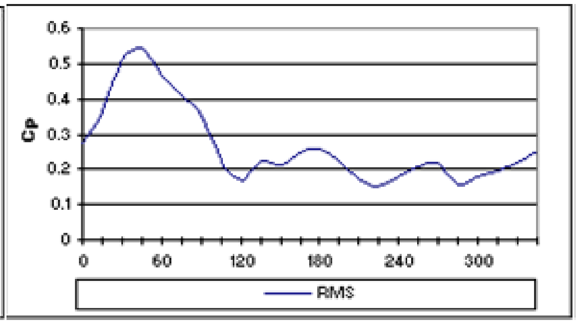

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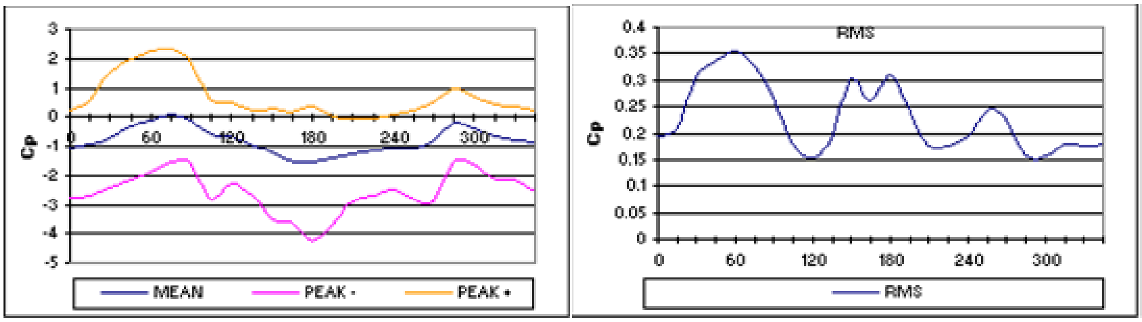

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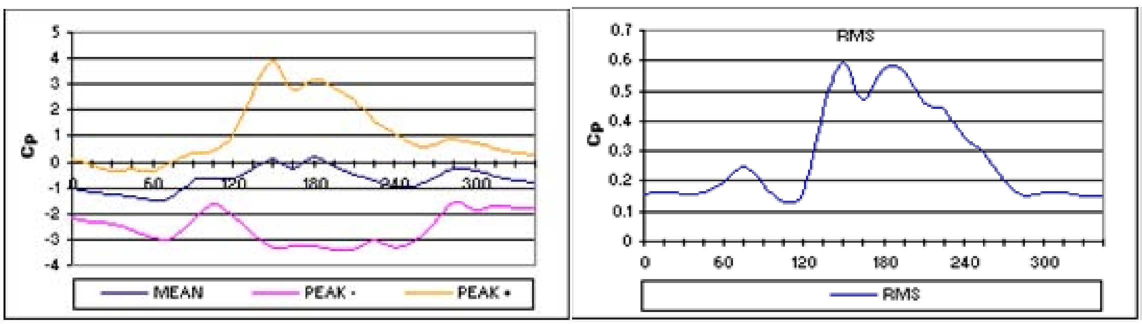

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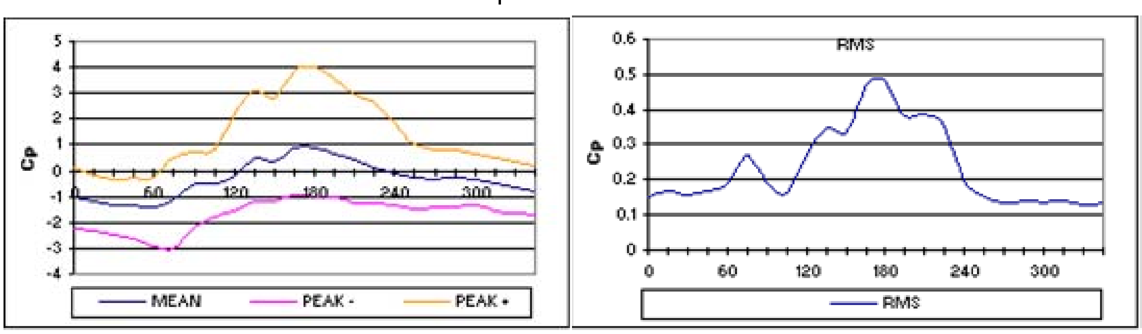

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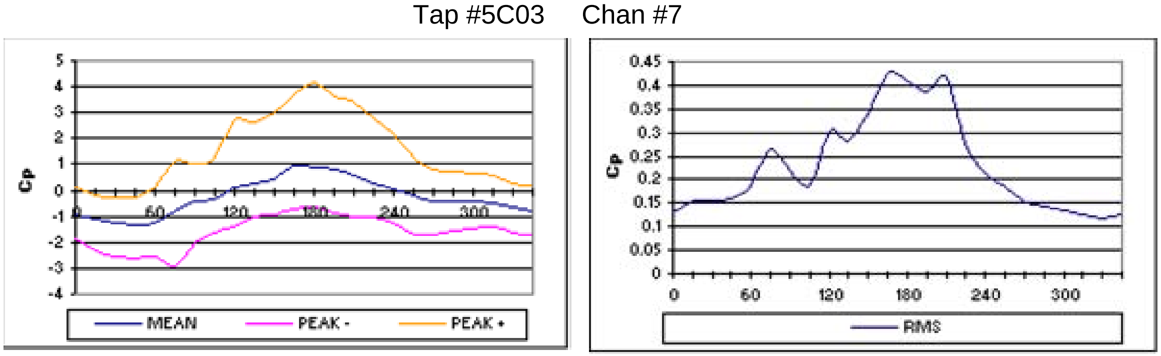

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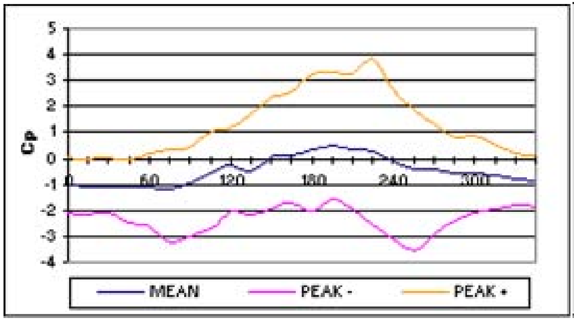

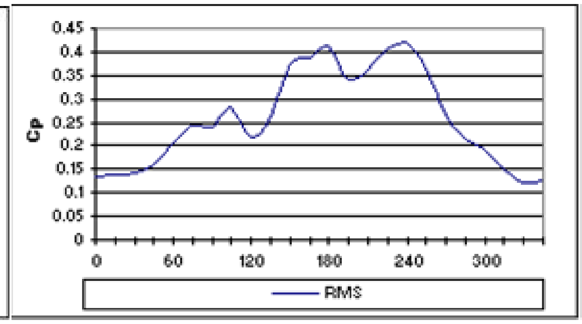

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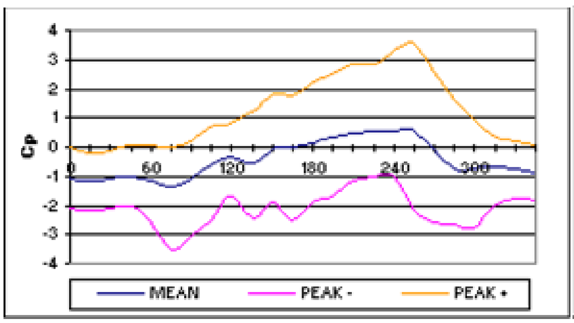

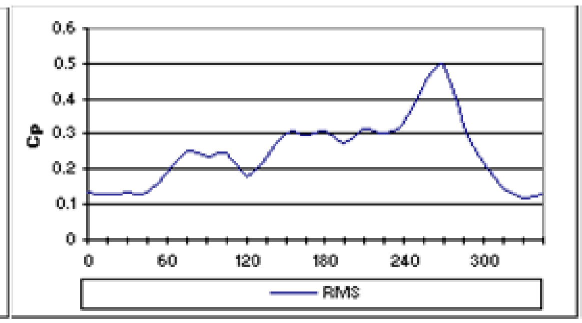

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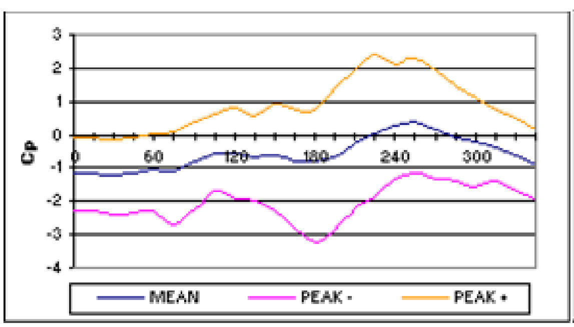

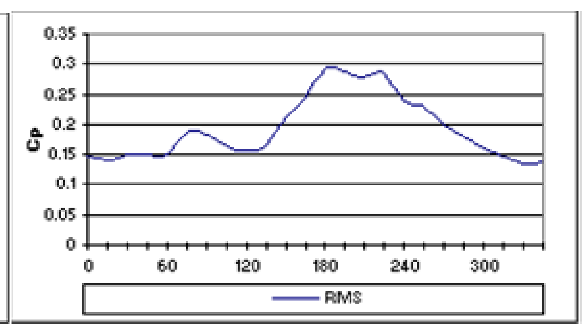

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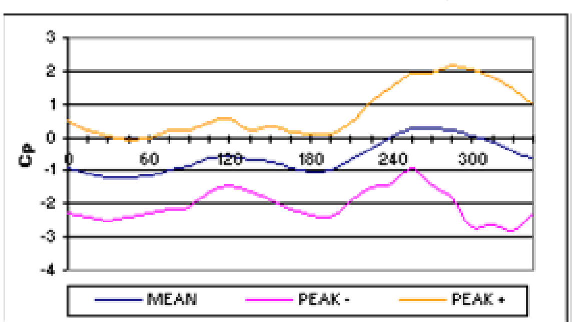

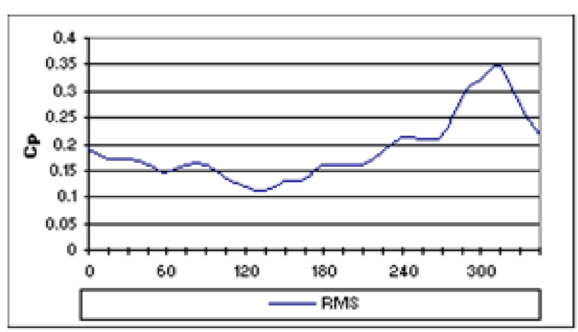

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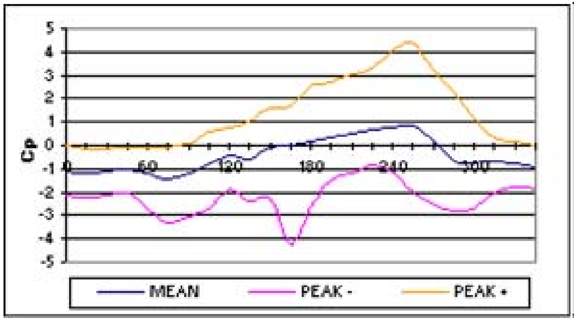

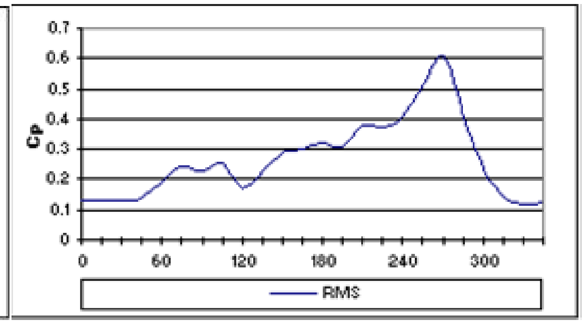

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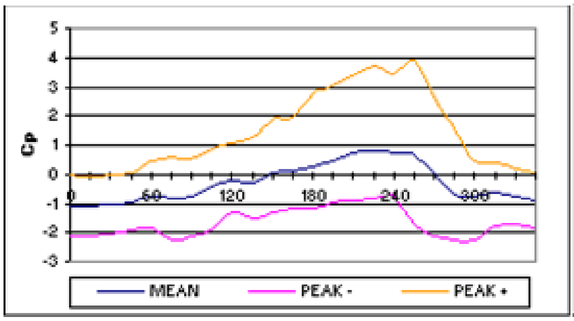

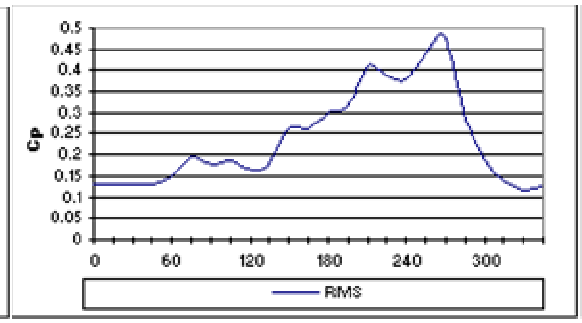

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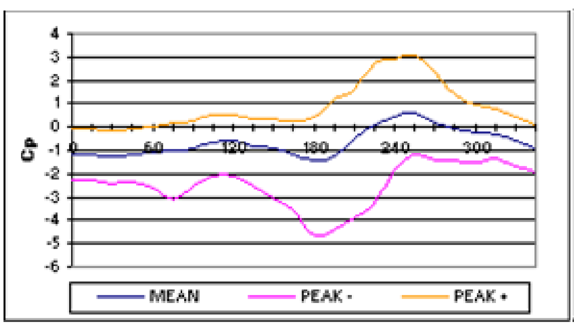

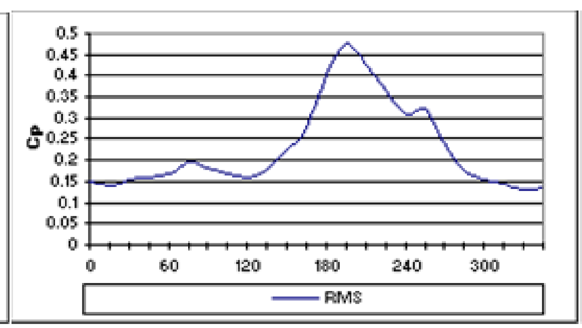

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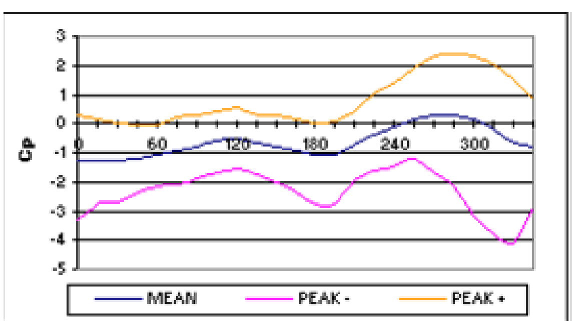

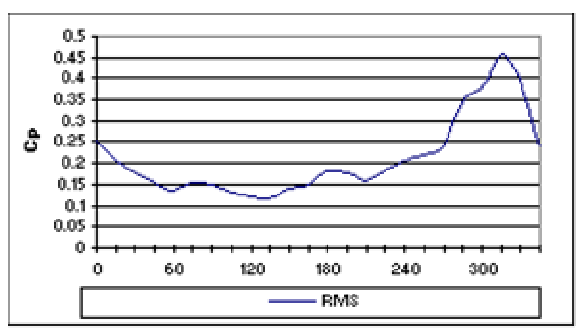

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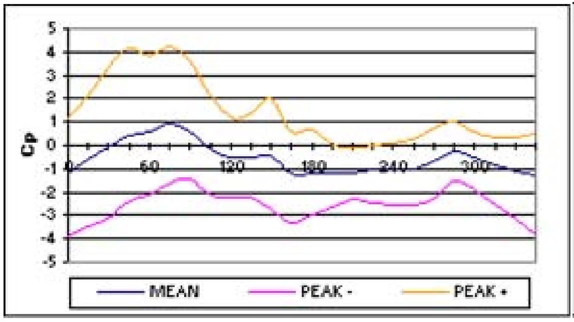

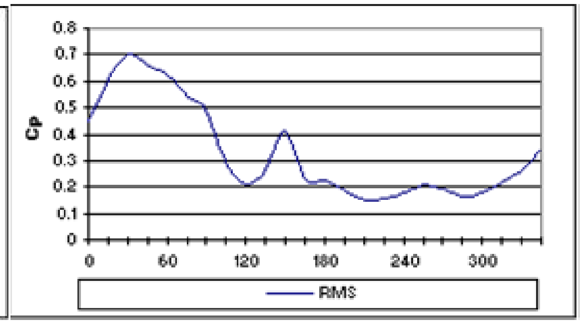

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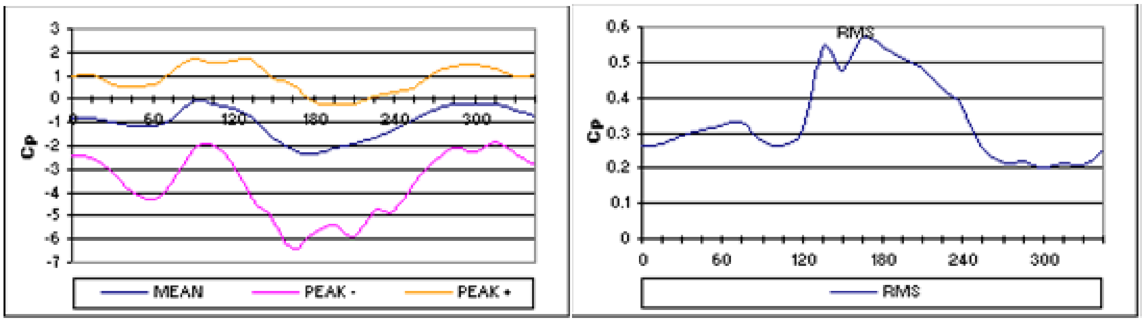

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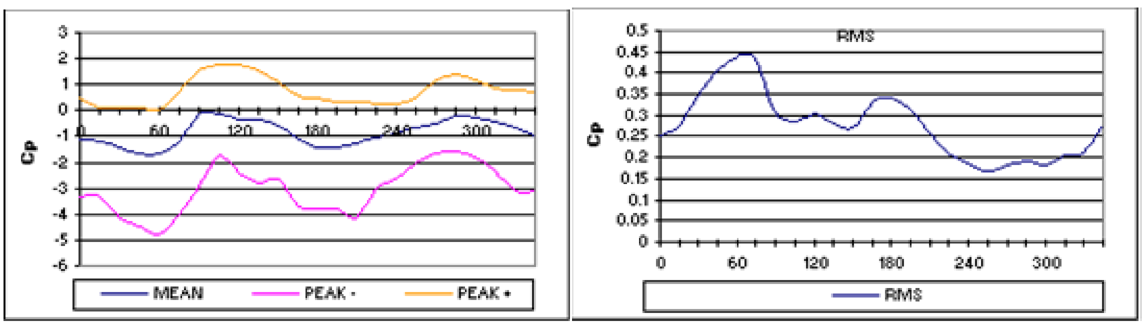

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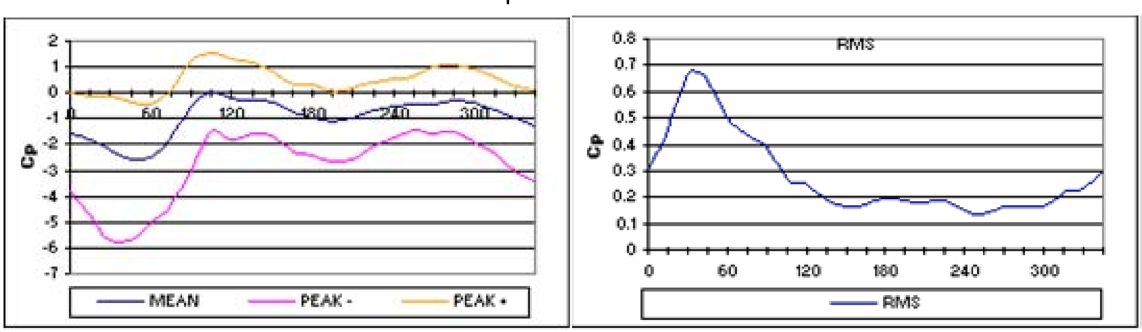

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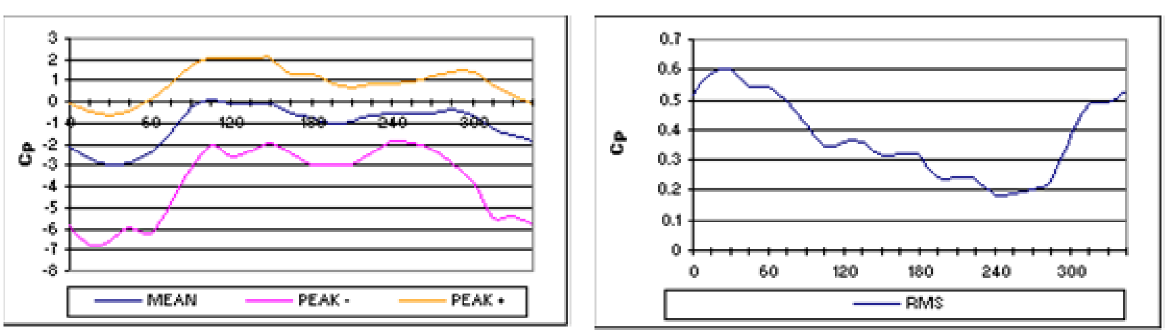

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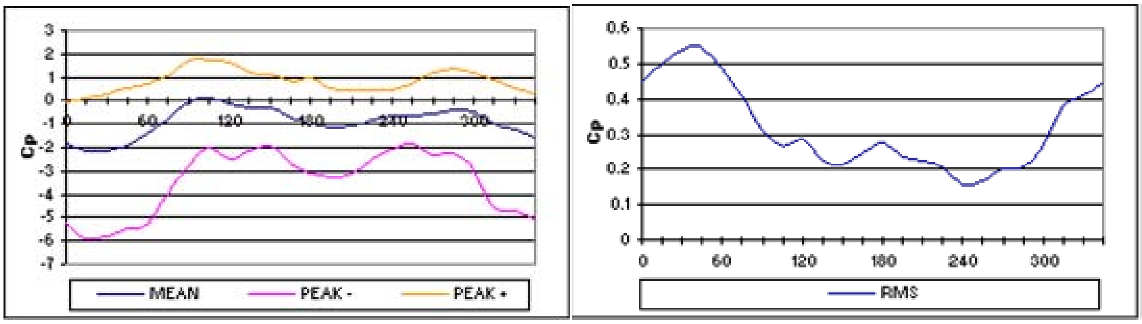

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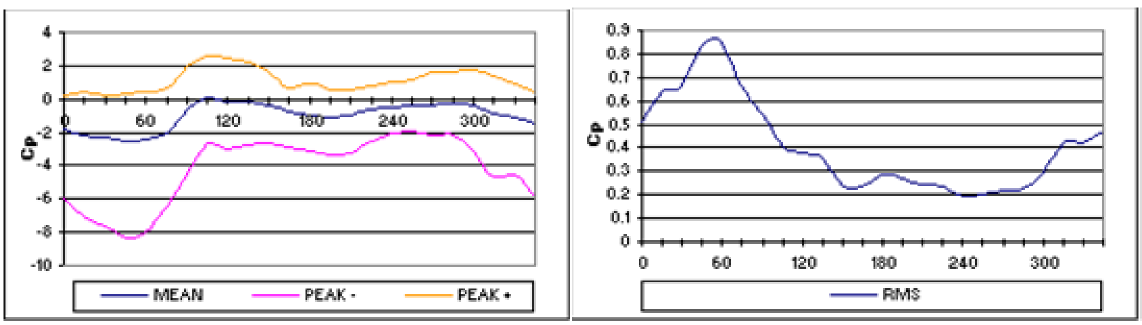

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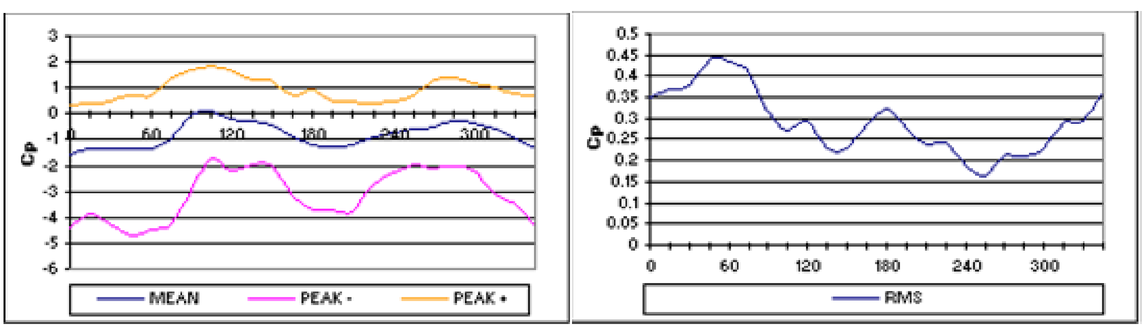

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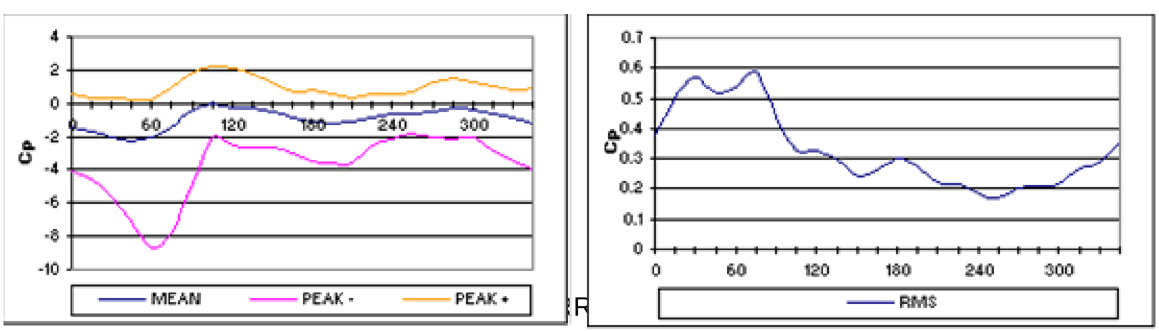

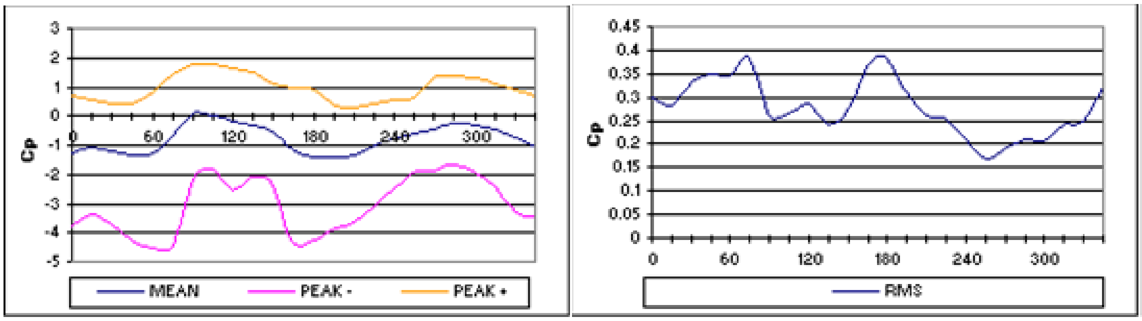

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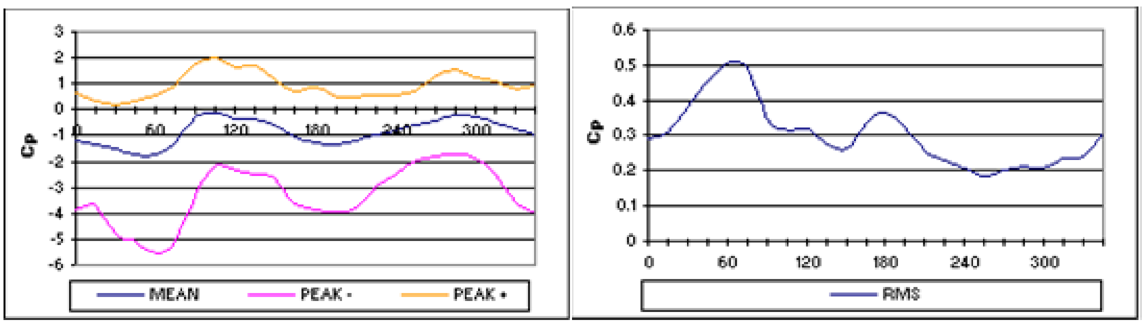

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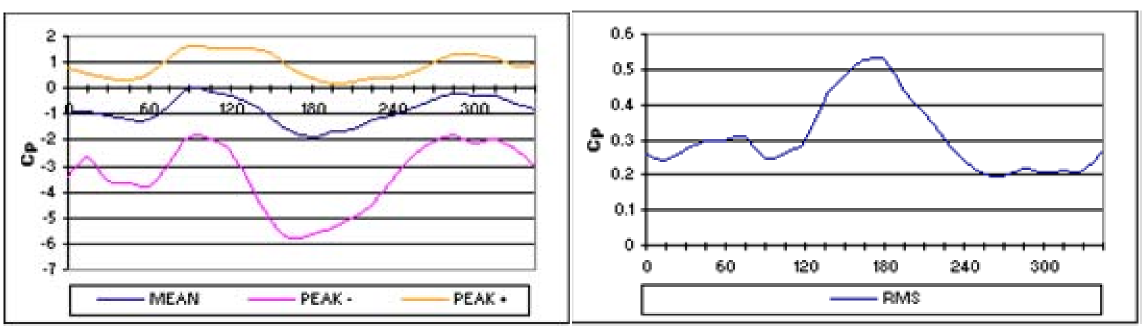

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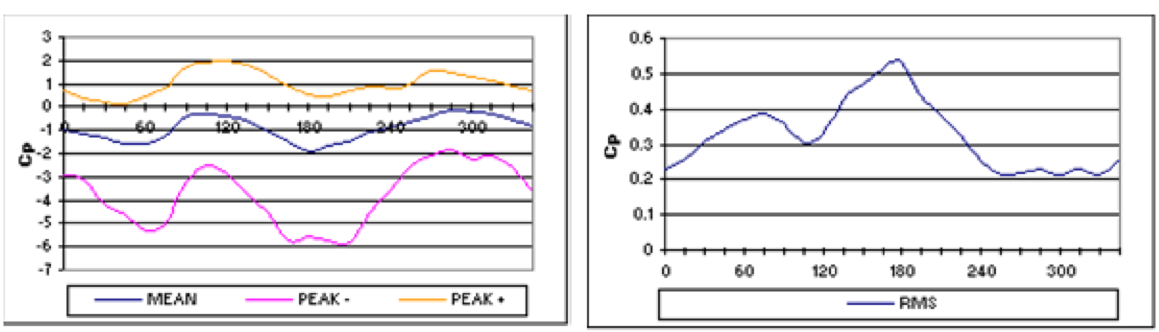

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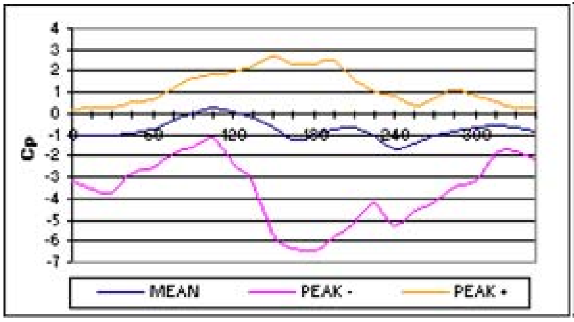

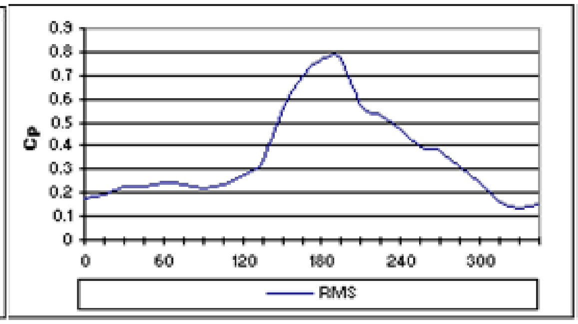

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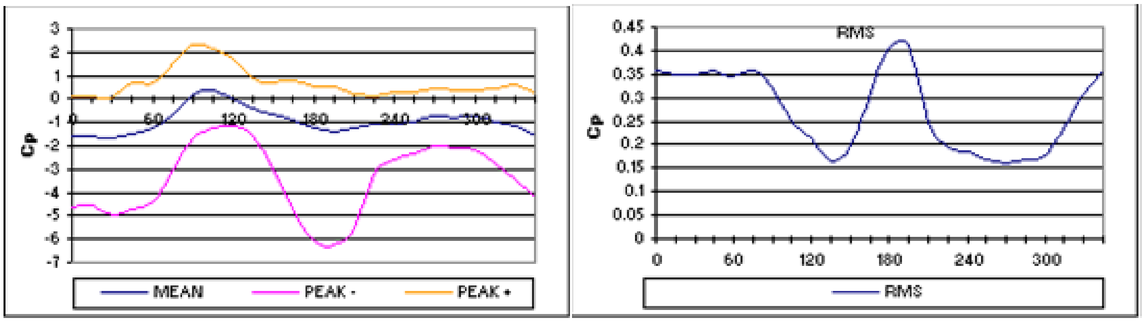

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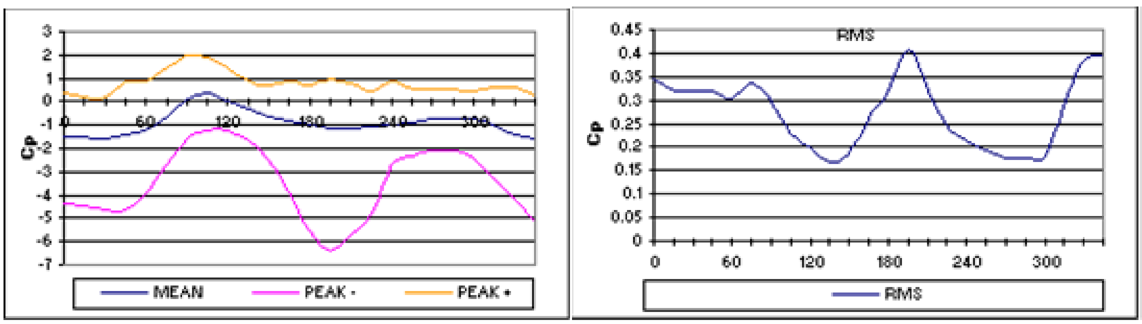

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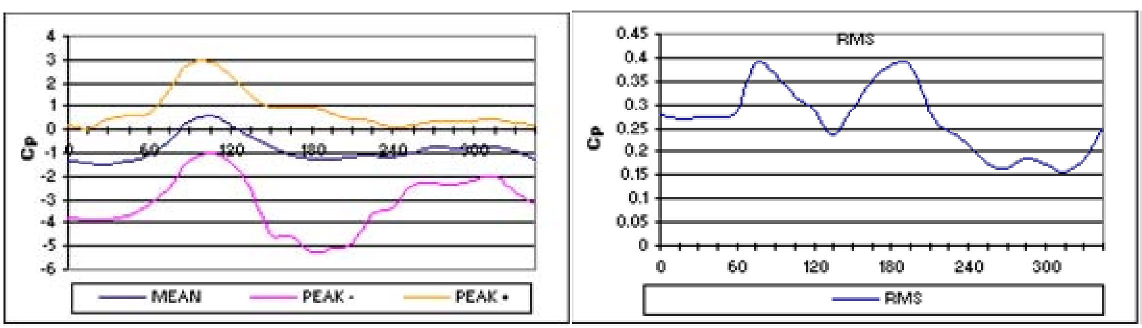

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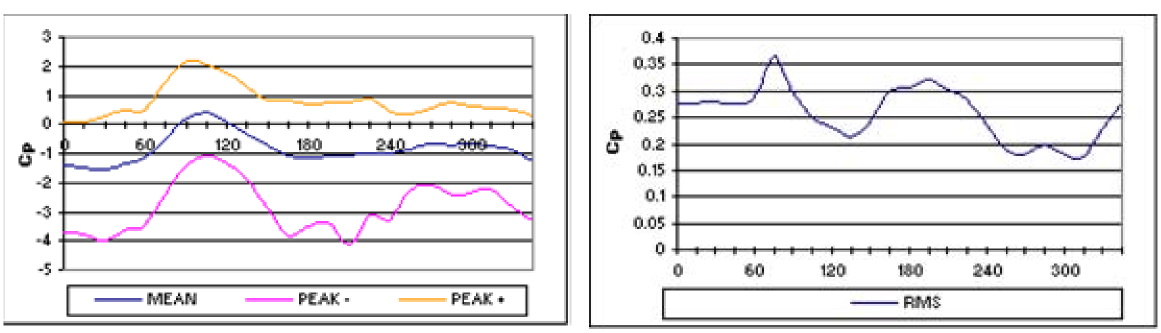

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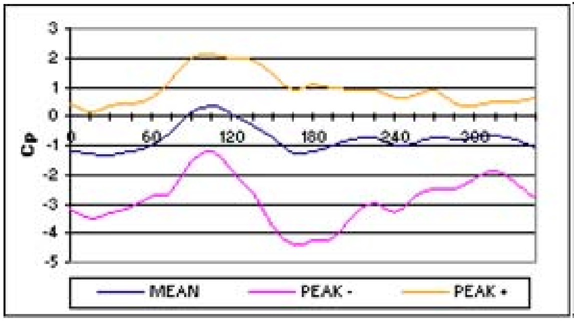

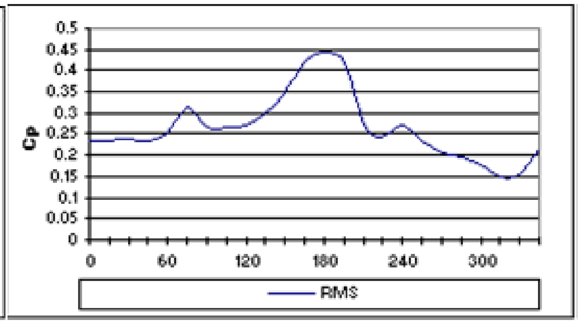

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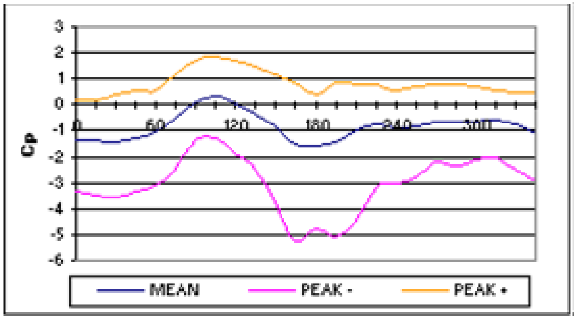

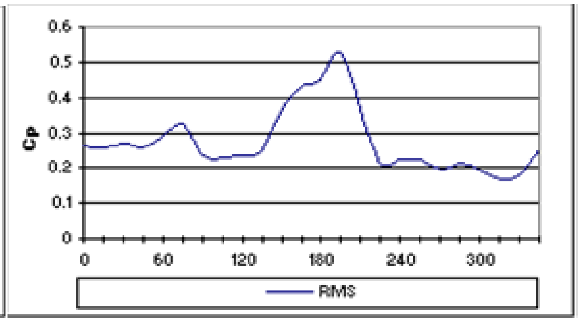

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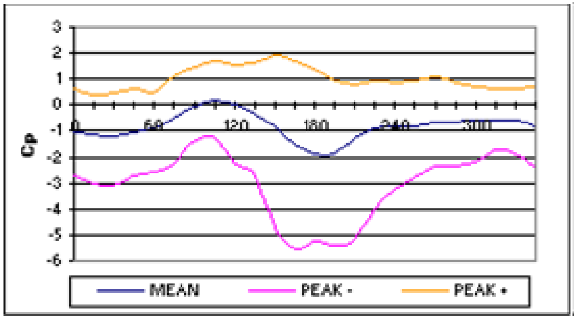

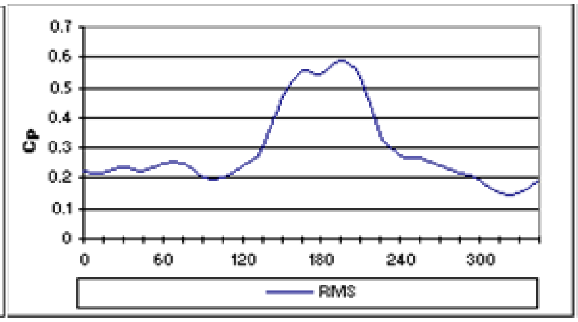

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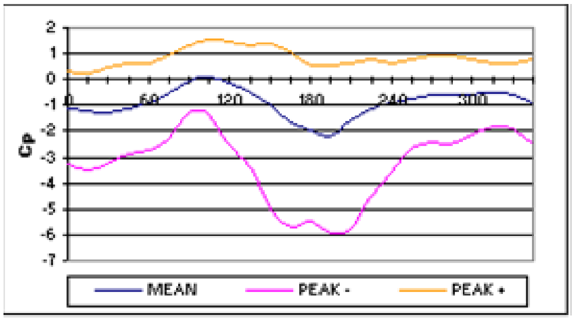

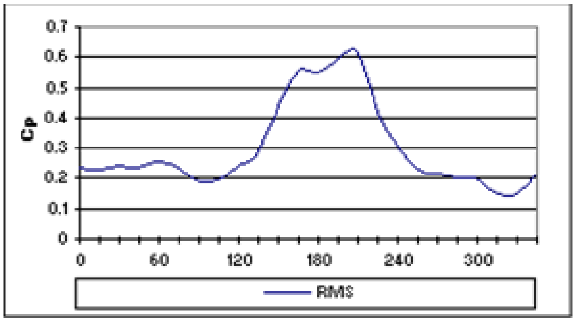

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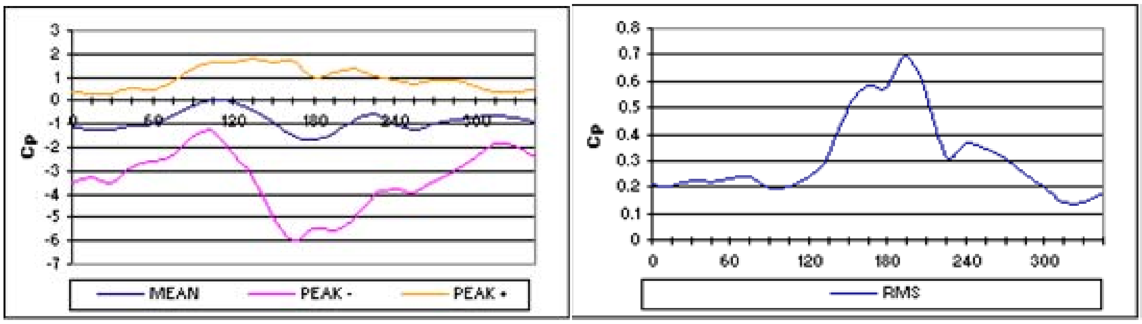

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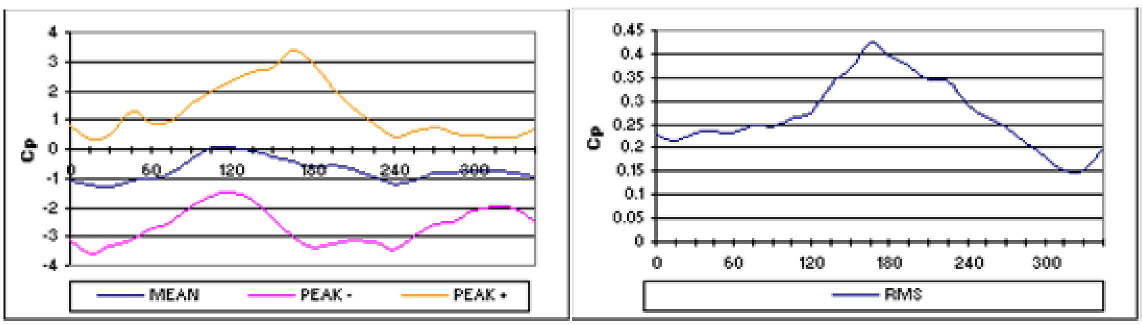

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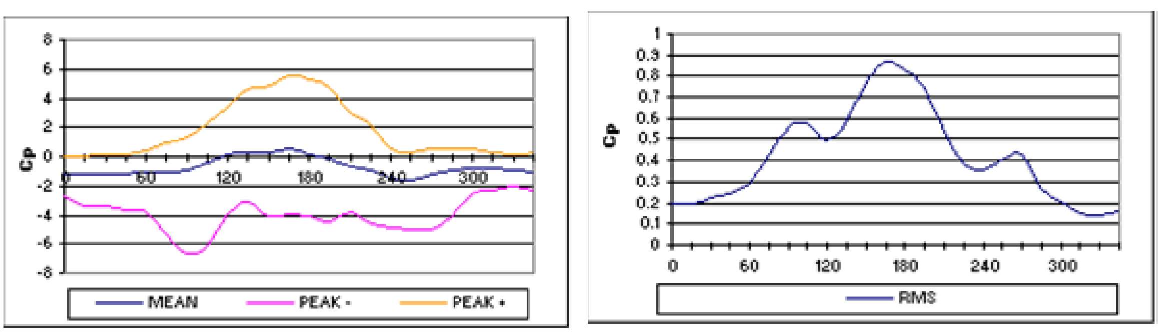

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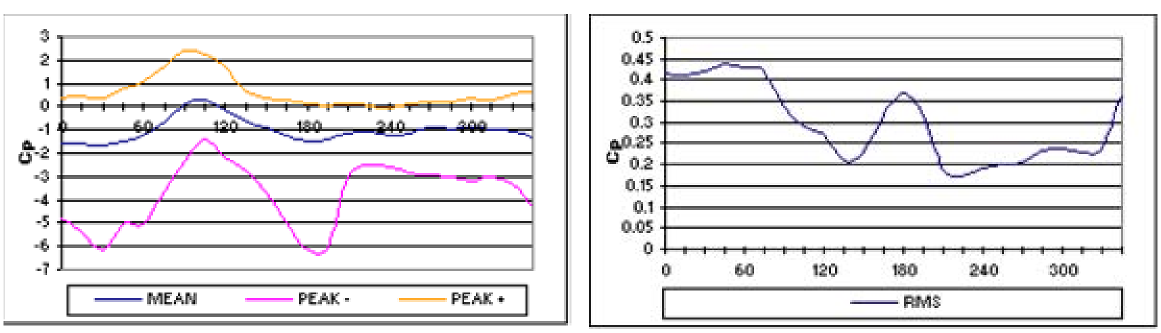

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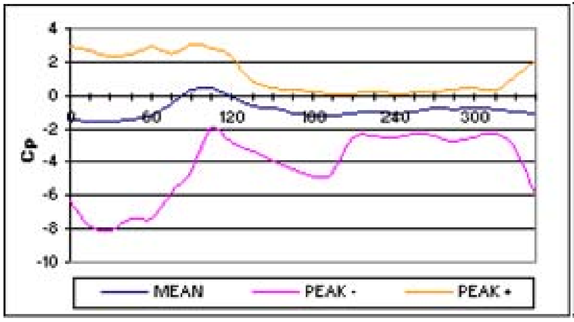

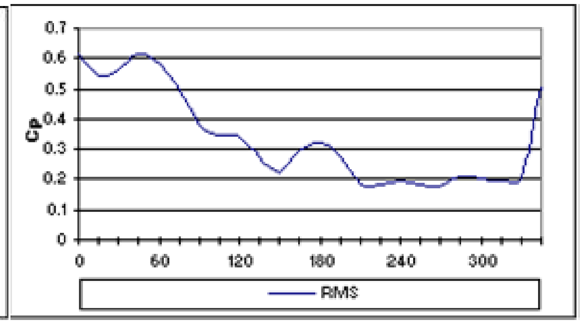

APPENDIX F

SHELTER REPORT

West Jefferson Medical Center Hurricane Sheltering Plan

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LSU Hurricane Center

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And

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F.1 INTRODUCTION

This document provides recommendations for operational hurricane sheltering plans for West Jefferson Medical Center (WJMC). It was developed as part of a multiyear, comprehensive hurricane vulnerability and mitigation study performed under contract with Jefferson Parish Emergency Management. The planning process included numerous site visits to WJMC and input from their staff. The mitigation plan and project technical data are included in separate reports.

LSU Hurricane Center researchers developed a new hurricane sheltering assessment and planning methodology to allow optimum use of the Medical Center facilities under a wide range of storm conditions. This methodology recognizes that hurricanes approaching south Louisiana from different directions can present different flood and wind hazards and develops plans accordingly.

F.2 PURPOSE

The purpose of this document is to provide a simple to use set of operational plans for different hurricane scenarios. These plans identify the different parts of the hospital complex that are vulnerable to wind and flood hazards and includes plans for where to move critical hospital functions that are in highly vulnerable areas to less vulnerable areas.

As a tropical storm or a hurricane enters the Gulf of Mexico it should be watched for intensity, forward speed, and predicted movement. As the storm begins to threaten the Louisiana/Mississippi Gulf region this report can be used to develop a specific sheltering plan

F.3 SHELTERING PLAN

This report contains two different wind sheltering plans and three different flood sheltering plans. These plans are used in different combinations depending on the various threats posed by the approaching hurricane. Table F.1 is the Hurricane Sheltering Plan Selection Matrix. This table is used to determine which flood sheltering plan and which wind sheltering plan should be used, depending on the approaching hurricane intensity and direction.

In Table F.1, Hurricane intensity is defined as the predicted Saffir-Simpson hurricane category at landfall. The ‘hurricane direction of travel’ is the anticipated storm track (i.e., the direction of motion of the storm). Note that this may be uncertain and a small range of directions may need to be considered. The flood plan used also depends on the astronomical tide expected when the storm makes landfall (either high tide or mean tide). Information on anticipated intensity at landfall and storm track and tides can be obtained from National Hurricane Center advisories, the local emergency management office, or National Weather Service office.

The flood depths indicated in Table F.1 are a range of possible values. These are given in feet of water above ground at the hospital site. Flood values were obtained from the NOAA SLOSH model, and do not include additional water levels from rainfall flooding, which could add as much as 1-2 feet to the ranges given. The wind speeds indicated on the table are for reference only, and are the anticipated range of wind speeds that will be experienced at the hospital location; accounting for initial landfall and inland decay.

The specific flood plans and wind plans called out in Table F.1 are provided in Appendix A. These plans are color-coded green, yellow, red, and gray, indicating the relative hazard level.

- Green –Low Hazard; Preferred Shelter Area
- Yellow – Moderate hazard, small possibility of a limited amount of floodwater (flood) and some broken windows (wind). Secondary Shelter Area

- Gray –Moderate Hazard –Walkways (wind plans only), should only be used when needed as walkways for travel between other shelter areas during the storm. Possibility of broken windows.
- Red – High hazard, should not be used during the storm; high hazard of significant flooding on that story (flood) and broken windows and roof damage (wind). Do Not Use as Shelter During Storm.

These same plans are also used to determine shelter areas. To determine the correct storm shelter plan for a given storm, a wind scenario and a flood scenario should be combined to create the overall shelter plan. If an area is green or yellow in one shelter plan and red in another, red will override and yellow will override green.

Begin by selecting the appropriate wind plan, Wind 1 or Wind 2, which provides the basic sheltering plan for the overall facility. The flood plans then determine if the first, second, and third floors should still be used or should be dropped form the overall shelter plan.

F.4 DEPARTMENTAL RELOCATION PLANS

If a portion of the structure housing a critical department is identified as having High Hazard on either of the wind plan or the flood plan for the incoming storm, the Department Relocation Table (Table F.2) should be used to determine the department's new location.

NOTE – this is not yet fully completed – further input from WJMC is required.

F.5 OTHER CONSIDERATIONS - Electrical and Mechanical Systems

Currently, the electrical switchboards are on the first floor and will no longer work once exposed to water. Therefore, in the scenarios for Flood 2 and 3, the hospital will not have any main or backup power.

F.6 SHELTER PLANS OVERVIEW

Flood 0 - Localized flooding due to extreme rainfall, presenting a moderate hazard.

Flood 1 - Storm surge flooding of as much as 12 feet above ground. This could inundate the first floor of the facility. The first floor should be completely evacuated.

Flood 2 - Storm surge flooding of as much as 22 ft above ground. This could inundate both the first and second floors. These two floors should be evacuated.

Wind 1 - Wind sheltering plan for moderate strength winds likely to cause minor damage. Primary hazard is broken windows due to small wind borne debris and roof covering damage that will cause roof leaks.

Wind 2 - Wind sheltering plan for extreme winds likely to cause significant damage. Wind hazards include a large amount of window failures due to debris and wind pressure, significant damage to roof structures and rooftop equipment, and large flying debris.

Table F.1 - Hurricane Sheltering Plan Selection Matrix

Predicted Saffir-Simpson Hurricane Category at Landfall	Hurricane Direction of Travel	Storm Landfall at Mean Tide		Storm Landfall at High Tide		Sustained Wind (mph)**	Peak Gust (mph)**	Wind Sheltering Plan
		Flood Depth* (ft)	Flood Sheltering Plan	Flood Depth* (ft)	Flood Sheltering Plan			
1	All	0	**Flood 0**	0	**Flood 0**	60 - 75	75 - 85	**Wind 1**
2	East North East North East North North East North North North West	0	**Flood 0**	0 – 10	**Flood 1**	75 - 85	85 - 105	**Wind 1**
	North West West North West West			0	**Flood 0**			
3	East North East North East	Up to 12	**Flood 1**	0 – 17	**Flood 2**	85 - 105	105 - 125	**Wind 2**
	North North East North North North West	Up to 14	**Flood 2**					
	North West	Up to 10	**Flood 1**	0 – 11	**Flood 1**			
	West North West	0	**Flood 0**					
	West			0	**Flood 0**			
4	East North East North East North North East North North North West	Up to 19	**Flood 2**	0 – 20	**Flood 2**	105 - 150	125 - 190	**Wind 2**
	North West	Up to 11	**Flood 1**					
	West North West West	Up to 5		0 – 13	**Flood 1**			
5	East North East North East North North East North North North West North West	Up to 22	**Flood 2**	0 – 22	**Flood 2**	> 150	> 190	**Wind 2**
	West North West West	Up to 15		0 -16				

* Estimated depth of flooding above ground at WJMC. **Estimated wind speeds at WJMC at 33 ft above ground.

Table F.2 - Department Relocation Plan

NOTE – THIS TABLE HAS NOT BEEN FULLY COMPLETED AND STILL NEEDS INPUT FROM WJMC

Department	Originally Designated Vertical Evacuation Area*	Wind 1 + Flood 0	Wind 1 + Flood 1	Wind 2 + Flood 0	Wind 2 + Flood 1	Wind 2 + Flood 2
Emergency Room	SDS	No move		No move		
Pharmacy	4 West Rehab Kitchen Area	No move	4 West Rehab Kitchen Area	No move		
Purchasing	Lounge Areas 5th & 7th Floor	No move	Lounge Areas 5th & 7th Floor			
Housekeeping	4 West Diabetes Classroom	No move	4 West Diabetes Classroom			
Radiology	ICU/CCU	No move	ICU/CCU	No move		
Nuclear/Radiation	Surgery	No move	Surgery	No move	Surgery	
Biomedical	8th Floor Physical Therapy Dept	No move	8th Floor Physical Therapy Dept.	No move		
Lab	5th South B wing Close to exterior stairwell	No move	5th South B wing Close to exterior stairwell	No move	5th South B wing	5th South B wing
Maintenance	5 South B wing	No move	5 South B wing	No move		
Central Control	Same Day Surgery Waiting					
Child Care	4 West Rehab	No move	4 West Rehab	No move	4 West Rehab	4 West Rehab
ICU/CCU		No move	No move			

- per WJMC Hurricane Disaster Plan

F.7 EXAMPLE

Consider Hurricane Lili as an example. Figures F.1-F.3 are the hurricane watch and warning graphic, strike probabilities, and forecast advisory associated for Hurricane Lili Advisory #43, respectively. This advisory was issued by the National Hurricane Center at 4:00 am CDT on October 2, 2002. The hurricane was a strong Category 2 storm at the time, with maximum sustained winds of 110 mph.

As shown in Figure F.1, landfall was predicted in south central Louisiana the following afternoon. Although the predicted track was not over Jefferson Parish, the parish was clearly within the cone of uncertainty. The Strike Probabilities (Figure F.2) indicated a 21% chance of the center of Hurricane Lili passing within 65 nautical miles of New Orleans at some time during the next three days.

In this situation – to determine what the operational shelter plan would be, the following steps would be taken.

Step 1 – Determine potential direction of travel of hurricane at landfall.

Figure F.1 shows the storm track curving fairly sharply near landfall. Likely potential tracks include north north west, north, and north north east. I a real scenario, this determination should be made with input from the local emergency management office and National Weather Service.

Step 2 – Determine predicted Saffir-Simpson Hurricane Intensity at landfall

The forecast advisory in Figure F.3 indicates anticipated sustained wind speed of 105 knots as the storm is approaching landfall. Converting to miles per hour (1 knot = 1.15 miles per hour, yields 121 mph. This corresponds to a Category 3 hurricane (see Appendix C under Saffir Simpson Scale)

Step 3 – Determine anticipated astronomical tide level at landfall (exact value isn't important – only is it near mean tide or less, or will it occur near high tide)

Tide information can be obtained from several sources, including the National Weather service. Depending on the level of uncertainty of the forecast time of landfall and the significant effects of astronomical tide on storm surge flood potential, it may be best to conservatively assume high tide unless forecasters are confident that time of landfall will definitely not coincide with high tide.

Step 4 – Use Table F.1 to determine appropriate flood and wind sheltering plans

For a category 3 storm heading north north west, north, or north north east, making landfall at mean tide or at high tide shows a potential for storm surge flooding of as much as 14 or 17 feet, respectively. In this case, both tide conditions call for using the **Flood 2** plan. A category 3 storm also calls using **Wind 2** sheltering plan.

The Flood and Wind Sheltering plans are located in Appendix A. Flood plan 2 indicates that the first and second floors may potentially be inundated and should not be used, leaving the areas indicated in the Wind 2 plan on third floor and above to be used for shelter space.

Step 5 – Use Table F.2 to determine department relocation plan

Use the column in Table F.2 for Wind 2 + Flood 2 to determine where the various departments should relocate to.

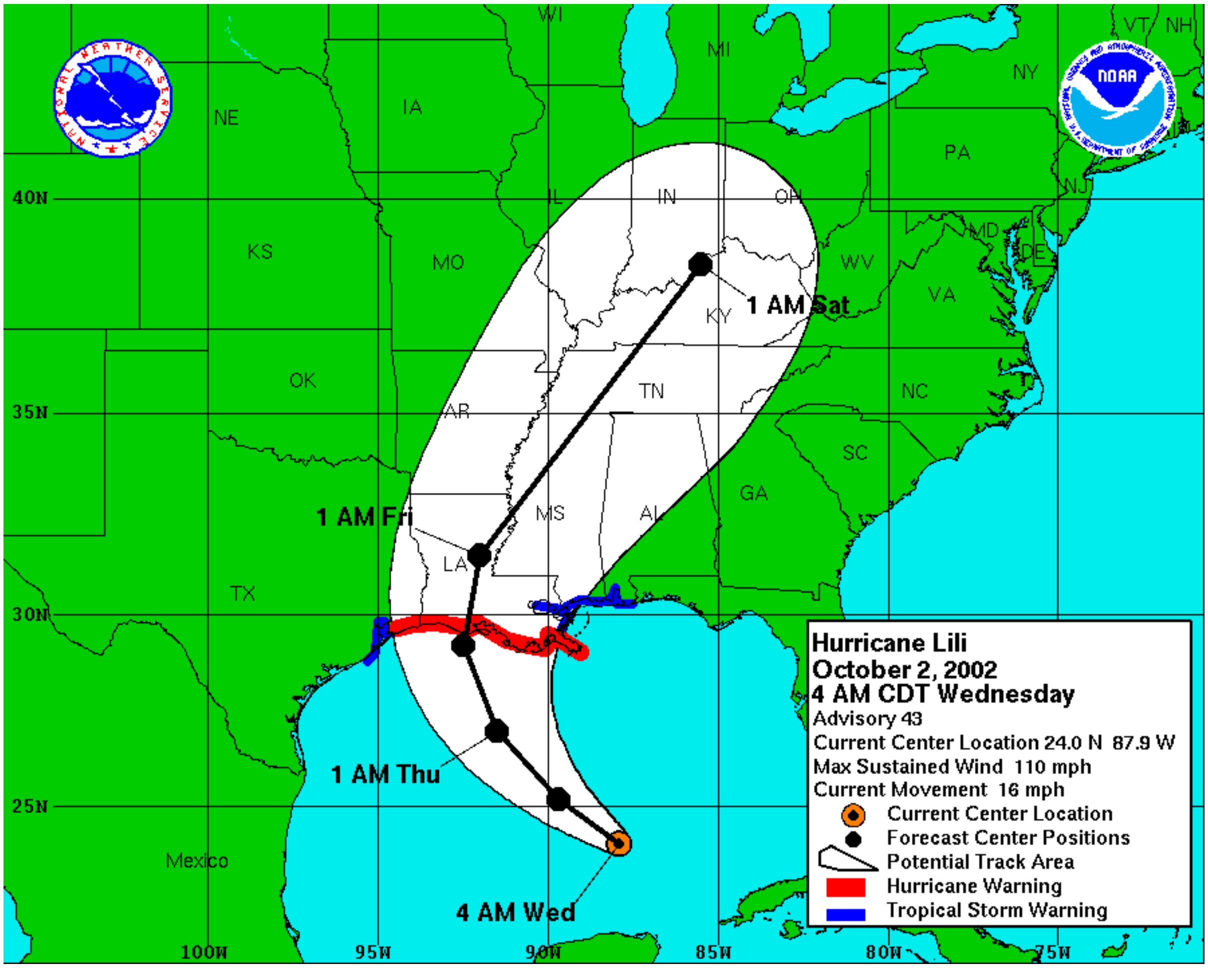

Figure F.1 - Watch and Warning Graphic for Advisory #43 for Hurricane Lili
(National Hurricane Center)

```
 ZCZC MIASPFAT3 ALL
TTAA00 KNHC DDHHMM
HURRICANE LILI PROBABILITIES NUMBER  43
NATIONAL WEATHER SERVICE MIAMI FL
4 AM CDT WED OCT 02 2002

PROBABILITIES FOR GUIDANCE IN HURRICANE PROTECTION
PLANNING BY GOVERNMENT AND DISASTER OFFICIALS

AT 4 AM CDT...0900Z...THE CENTER OF LILI WAS LOCATED NEAR
LATITUDE 24.0 NORTH...LONGITUDE  87.9 WEST

CHANCES OF CENTER OF THE HURRICANE PASSING WITHIN 65 NAUTICAL MILES
OF LISTED LOCATIONS THROUGH  1AM CDT SAT OCT  5 2002

LOCATION           A  B  C  D  E   LOCATION           A  B  C  D  E

27.0N  91.5W      40  X  X  X 40   PORT ARTHUR TX     X 22  2  1 25
29.2N  92.5W       2 27  X  1 30   GALVESTON TX       X 19  2  X 21
31.5N  92.0W       X 11 11  1 23   FREEPORT TX        X 15  2  X 17
SAVANNAH GA        X  X  X  2  2   PORT O CONNOR TX   X  7  2  1 10
ST MARKS FL        X  X  X  3  3   CORPUSCHRISTI TX   X  1  1  X  2
APALACHICOLA FL    X  X  X  3  3   GULF 29N 85W       X  X  X  2  2
PANAMA CITY FL     X  X  1  4  5   GULF 29N 87W       X  1  3  3  7
PENSACOLA FL       X  1  4  6 11   GULF 28N 89W      13  5  X  1 19
MOBILE AL          X  2  8  4 14   GULF 28N 91W      26  6  X  X 32
GULFPORT MS        X  7  7  2 16   GULF 28N 93W      16 15  X  X 31
BURAS LA           2 13  3  X 18   GULF 28N 95W       2 15  X  1 18
NEW ORLEANS LA     X 17  3  1 21   GULF 27N 96W       1  4  1  1  7
NEW IBERIA LA      X 24  2  X 26

COLUMN DEFINITION   PROBABILITIES IN PERCENT
A IS PROBABILITY FROM NOW TO  1AM THU
FOLLOWING ARE ADDITIONAL PROBABILITIES
B FROM  1AM THU TO  1PM THU
C FROM  1PM THU TO  1AM FRI
D FROM  1AM FRI TO  1AM SAT
E IS TOTAL PROBABILITY FROM NOW TO  1AM SAT
X MEANS LESS THAN ONE PERCENT

FORECASTER PASCH
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Figure F.2 - Hurricane Lili Strike Probabilities for Advisory #43
(National Hurricane Center)

```
ZCZC MIATCMAT3 ALL
TTAA00 KNHC DDHHMM
HURRICANE LILI FORECAST/ADVISORY NUMBER  43
NATIONAL WEATHER SERVICE MIAMI FL   AL1302
0900Z WED OCT 02 2002

AT 4 AM CDT...0900Z...A HURRICANE WARNING HAS BEEN ISSUED FROM EAST
OF HIGH ISLAND TEXAS TO THE MOUTH OF THE MISSISSIPPI RIVER.

ALSO AT 4 AM CDT...0900Z...A TROPICAL STORM WARNING HAS BEEN ISSUED
FROM FREEPORT TO HIGH ISLAND TEXAS...AND FROM EAST OF THE MOUTH OF
THE MISSISSIPPI RIVER TO THE ALABAMA/FLORIDA BORDER...INCLUDING NEW
ORLEANS AND LAKE PONTCHARTRAIN.

AT 4 AM CDT...0900Z...THE GOVERNMENT OF MEXICO HAS DISCONTINUED THE
TROPICAL STORM WATCH FOR THE NORTH COAST OF THE YUCATAN PENINSULA
FROM COZUMEL TO PROGRESO.

HURRICANE CENTER LOCATED NEAR 24.0N  87.9W AT 02/0900Z
POSITION ACCURATE WITHIN  20 NM

PRESENT MOVEMENT TOWARD THE WEST-NORTHWEST OR 300 DEGREES AT  14 KT

ESTIMATED MINIMUM CENTRAL PRESSURE  955 MB
MAX SUSTAINED WINDS  95 KT WITH GUSTS TO 115 KT.
64 KT....... 40NE  25SE  20SW  35NW.
50 KT....... 70NE  50SE  40SW  70NW.
34 KT.......160NE 125SE  75SW 140NW.
12 FT SEAS..210NE 150SE 100SW 140NW.
WINDS AND SEAS VARY GREATLY IN EACH QUADRANT.  RADII IN NAUTICAL
MILES ARE THE LARGEST RADII EXPECTED ANYWHERE IN THAT QUADRANT.

REPEAT...CENTER LOCATED NEAR 24.0N  87.9W AT 02/0900Z
AT 02/0600Z CENTER WAS LOCATED NEAR 23.6N  87.2W

FORECAST VALID 02/1800Z 25.2N  89.7W
MAX WIND 100 KT...GUSTS 120 KT.
64 KT... 40NE  25SE  20SW  35NW.
50 KT... 70NE  50SE  40SW  70NW.
34 KT...160NE 125SE  75SW 140NW.

FORECAST VALID 03/0600Z 27.0N  91.5W
MAX WIND 105 KT...GUSTS 130 KT.
64 KT... 40NE  25SE  25SW  35NW.
50 KT... 70NE  60SE  50SW  70NW.
34 KT...160NE 140SE  90SW 150NW.

FORECAST VALID 03/1800Z 29.2N  92.5W
MAX WIND 105 KT...GUSTS 130 KT.
64 KT... 45NE  35SE  25SW  35NW.
50 KT... 75NE  60SE  60SW  60NW.
34 KT...160NE 160SE 110SW 120NW.

REQUEST FOR 3 HOURLY SHIP REPORTS WITHIN 300 MILES OF 24.0N  87.9W

EXTENDED OUTLOOK...USE FOR GUIDANCE ONLY...ERRORS MAY BE LARGE

OUTLOOK VALID 04/0600Z 31.5N  92.0W...INLAND
MAX WIND  50 KT...GUSTS  60 KT.
50 KT... 40NE  40SE  40SW  40NW.
34 KT... 90NE  90SE  90SW  90NW.

OUTLOOK VALID 05/0600Z 38.5N  85.5W...INLAND...EXTRATROPICAL
MAX WIND  20 KT...GUSTS  25 KT.

NEXT ADVISORY AT 02/1500Z

FORECASTER PASCH
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Figure F.3 - Hurricane Lili Forecast Advisory #43
(National Hurricane Center)

APPENDIX F1

FLOOD AND WIND SHELTERING PLAN

Table F1.1 - Flood Sheltering Plans

	Flood Plan		
	Flood 0	**Flood 1**	**Flood 2**
Expected Flood Depth / Floor of Hospital	0* ft	Up to 12 ft	Up to 22 ft
1	**Moderate Hazard**	**High Hazard**	
2	**Low Hazard**	**Moderate Hazard**	**High Hazard**
3	**Low Hazard**		**Moderate Hazard**
4	**Low Hazard**		
5	**Low Hazard**		
6	**Low Hazard**		
7	**Low Hazard**		
8	**Low Hazard**		

*Flood due to rainfall varies

Flood 0 - Localized flooding due to extreme rainfall, presenting a moderate hazard.

Flood 1 - Storm surge flooding of as much as 12 feet above ground. This could inundate the first floor of the facility. The first floor should be completely evacuated.

Flood 2 - Storm surge flooding of as much as 22 ft above ground. This could inundate both the first and second floors. These two floors should be evacuated.

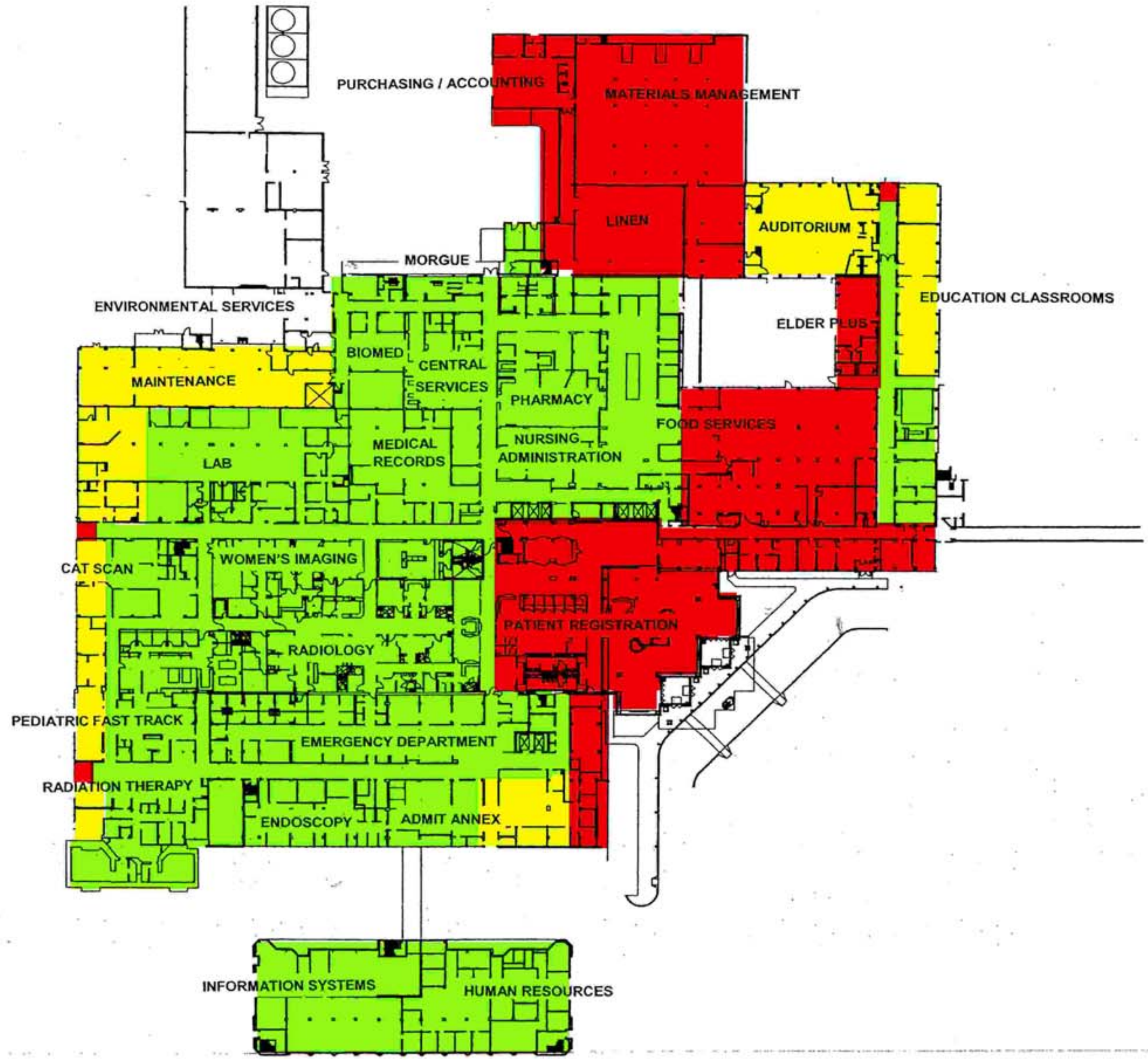
Wind Shelter Plans

Wind 1 - Wind sheltering plan for moderate strength winds likely to cause minor damage. Primary hazard is broken windows due to small wind borne debris and roof covering damage that will cause roof leaks.

Wind 2 - Wind sheltering plan for extreme winds likely to cause significant damage. Wind hazards include a large amount of window failures due to debris and wind pressure, significant damage to roof structures and rooftop equipment, and large flying debris.

WIND 1 SHELTER PLAN

1st Floor



Preferred Shelter Area (Low Hazard)

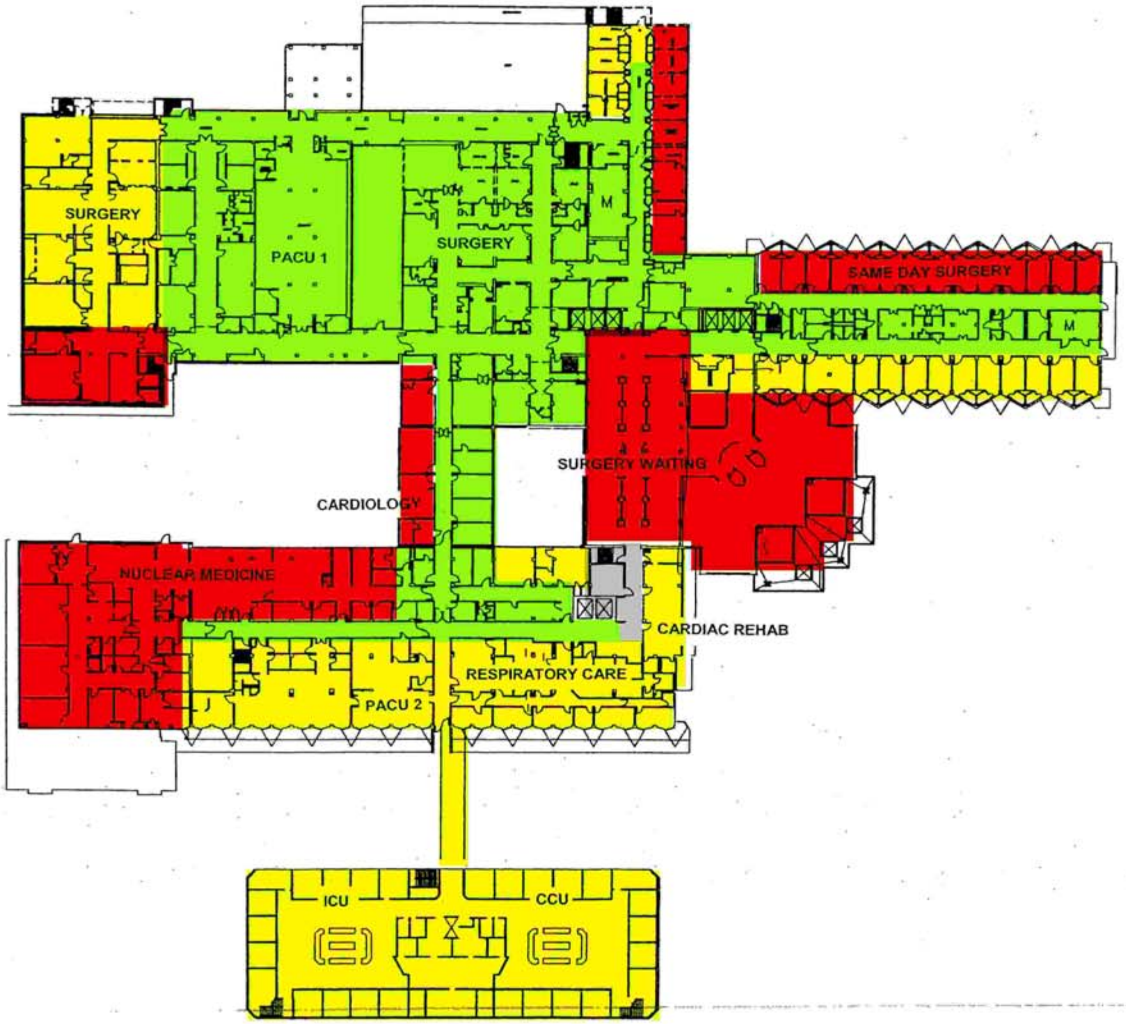
Secondary Shelter Area (Moderate Hazard)

Walkways
For travel between shelter areas only–no loitering
(Moderate Hazard)

Do Not Use for Shelter (High Hazard)

WIND 1
SHELTER PLAN

2nd Floor



Preferred Shelter Area
(Low Hazard)

Secondary Shelter Area
(Moderate Hazard)

Walkway
For travel between Shelter area
only-no loitering
(Moderate Hazard)

Do Not Use for Shelter

WIND 1 SHELTER PLAN

3rd Floor

Preferred Shelter Area (Low Hazard)

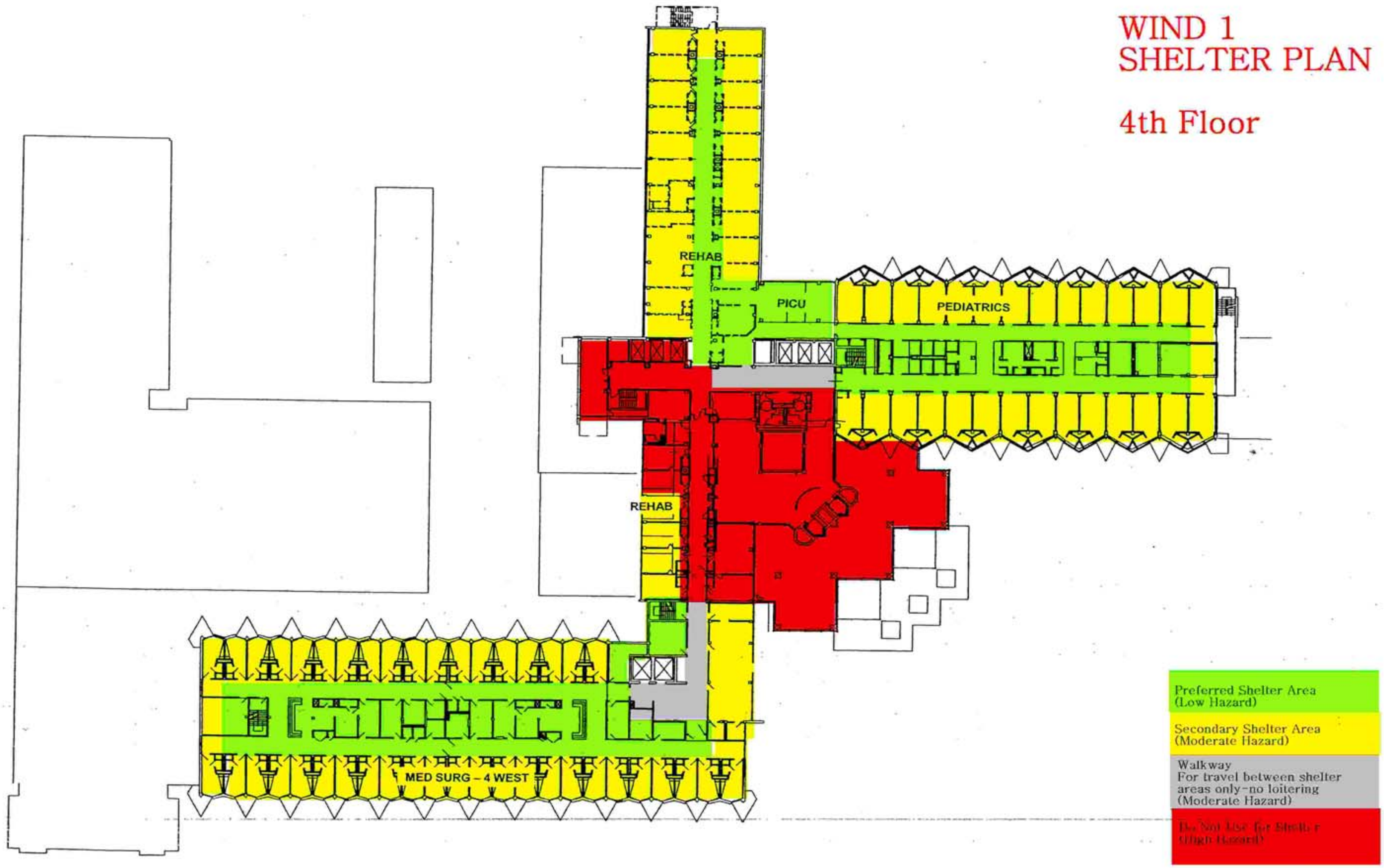
Secondary Shelter Area (Moderate Hazard)

Walkway
For travel between Shelter Area only–no loitering (Moderate Hazard)

Do Not Use for Shelter (High Hazard)

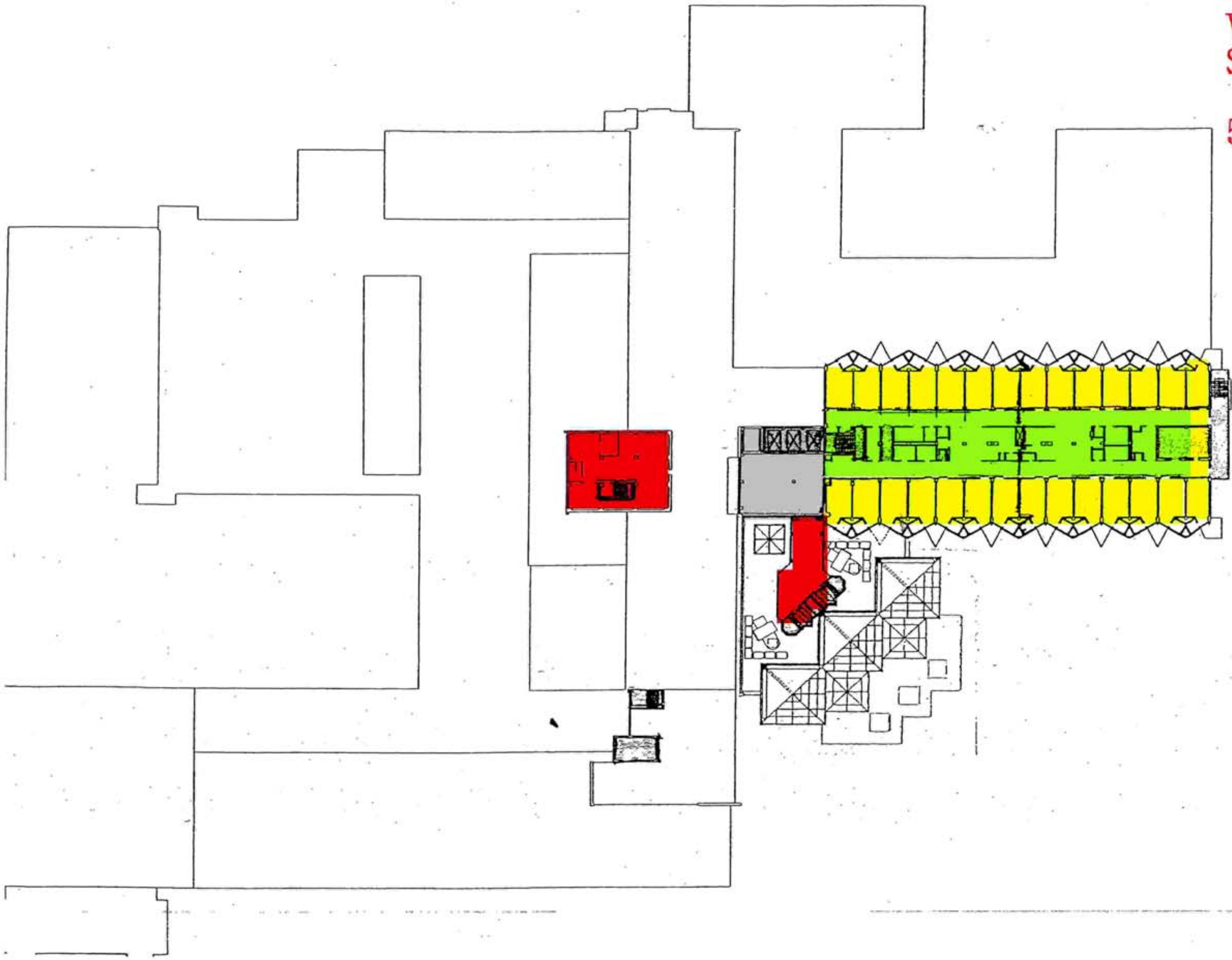
WIND 1 SHELTER PLAN

4th Floor



WIND 1 SHELTER PLAN

5th Floor



Preferred Shelter Area
(Low Hazard)

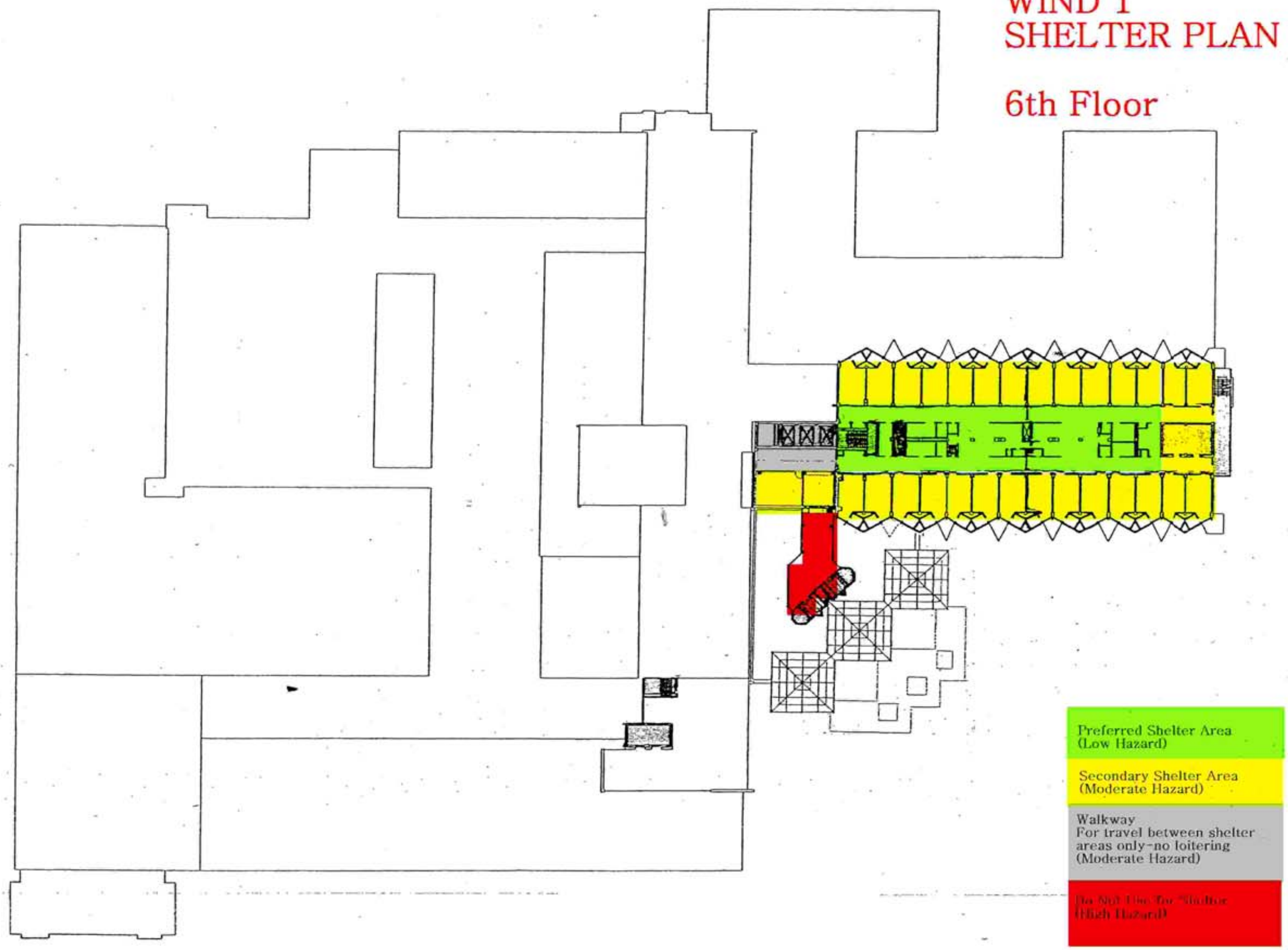
Secondary Shelter Area
(Moderate Hazard)

Walkway
For travel between shelter
areas only-no loitering
(Moderate Hazard)

Do Not Use for Shelter

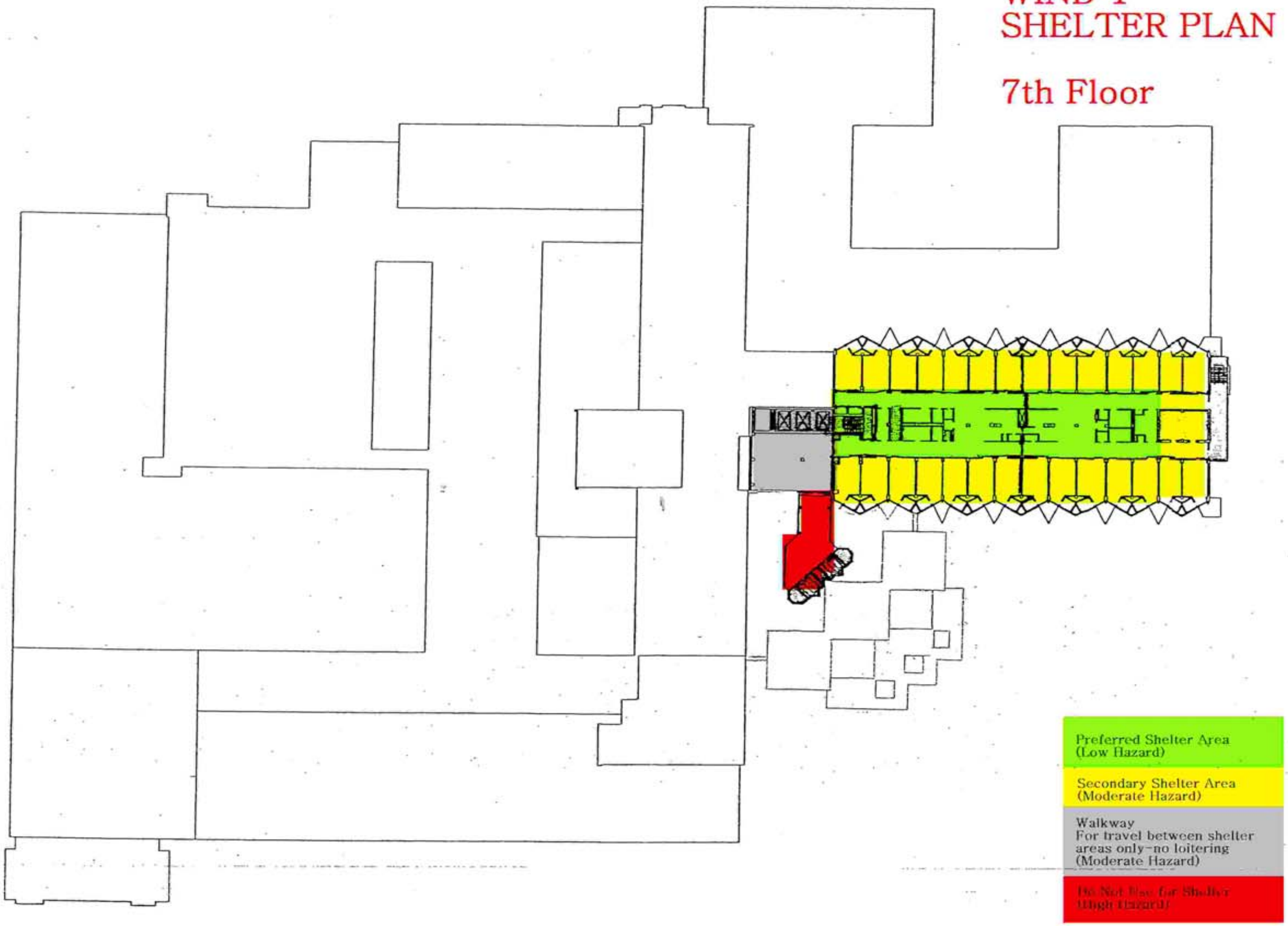
WIND 1
SHELTER PLAN

6th Floor



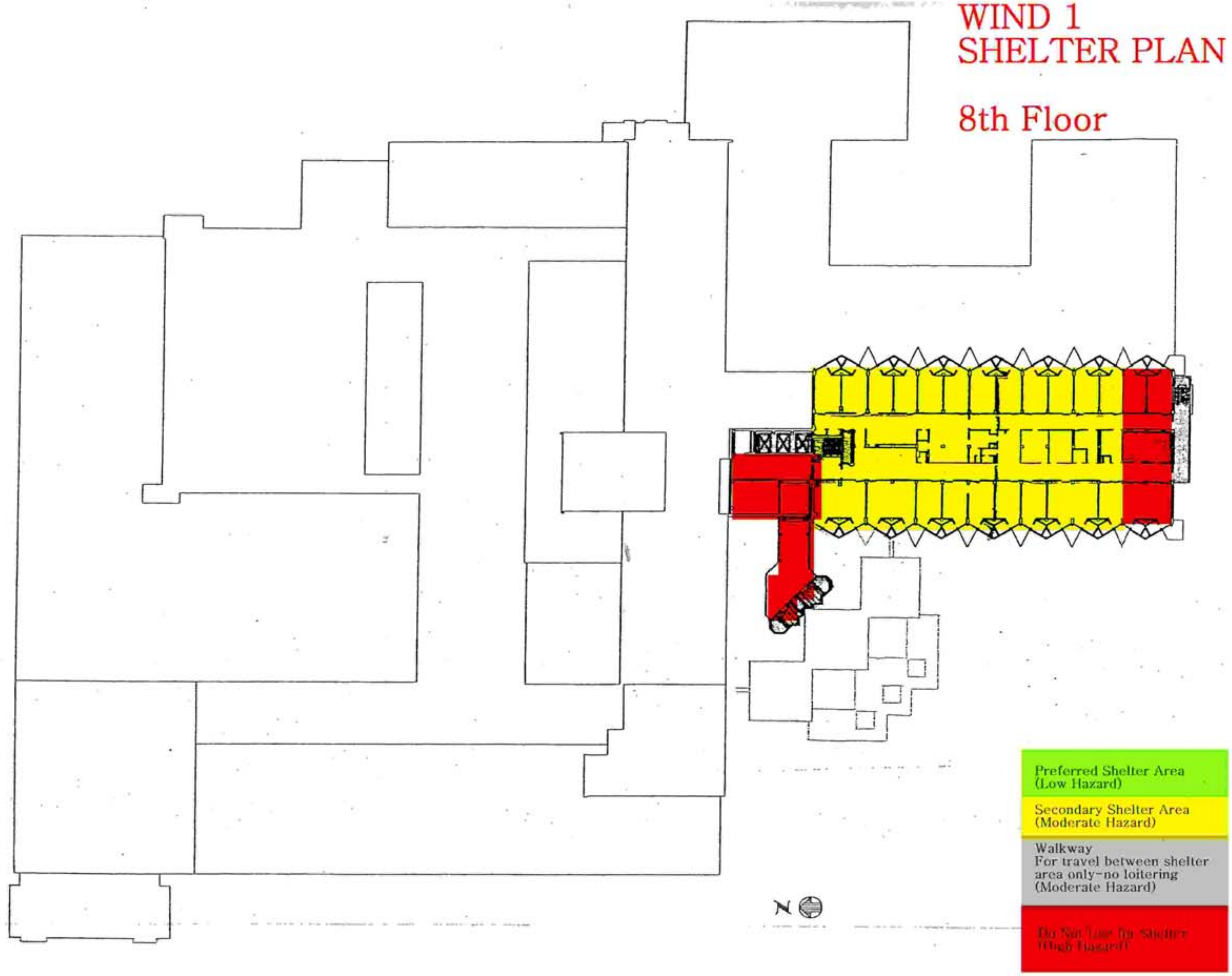
WIND 1 SHELTER PLAN

7th Floor



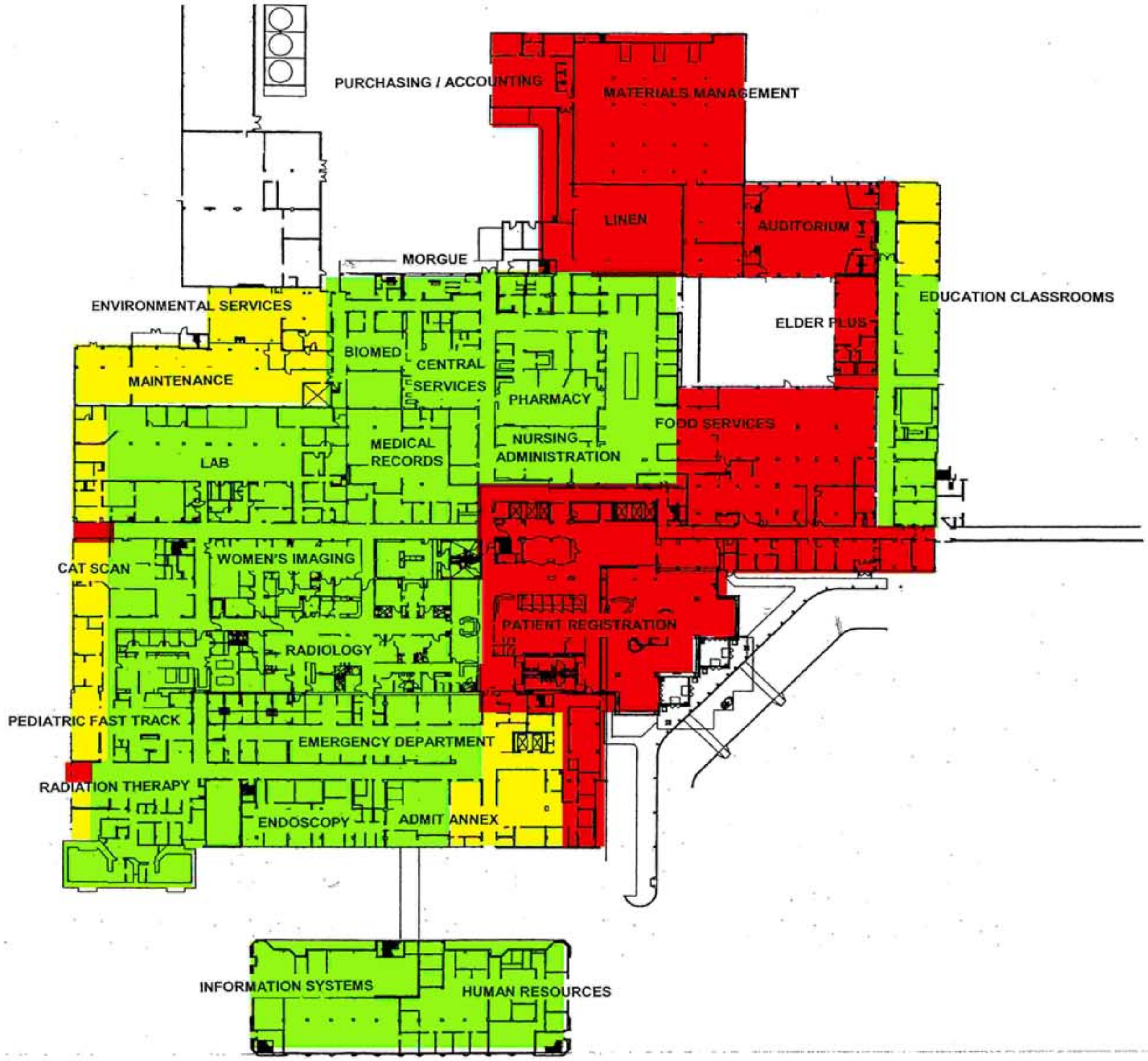
WIND 1
SHELTER PLAN

8th Floor



WIND 2 SHELTER PLAN

1st Floor



Preferred Shelter Area
(Low Hazard)

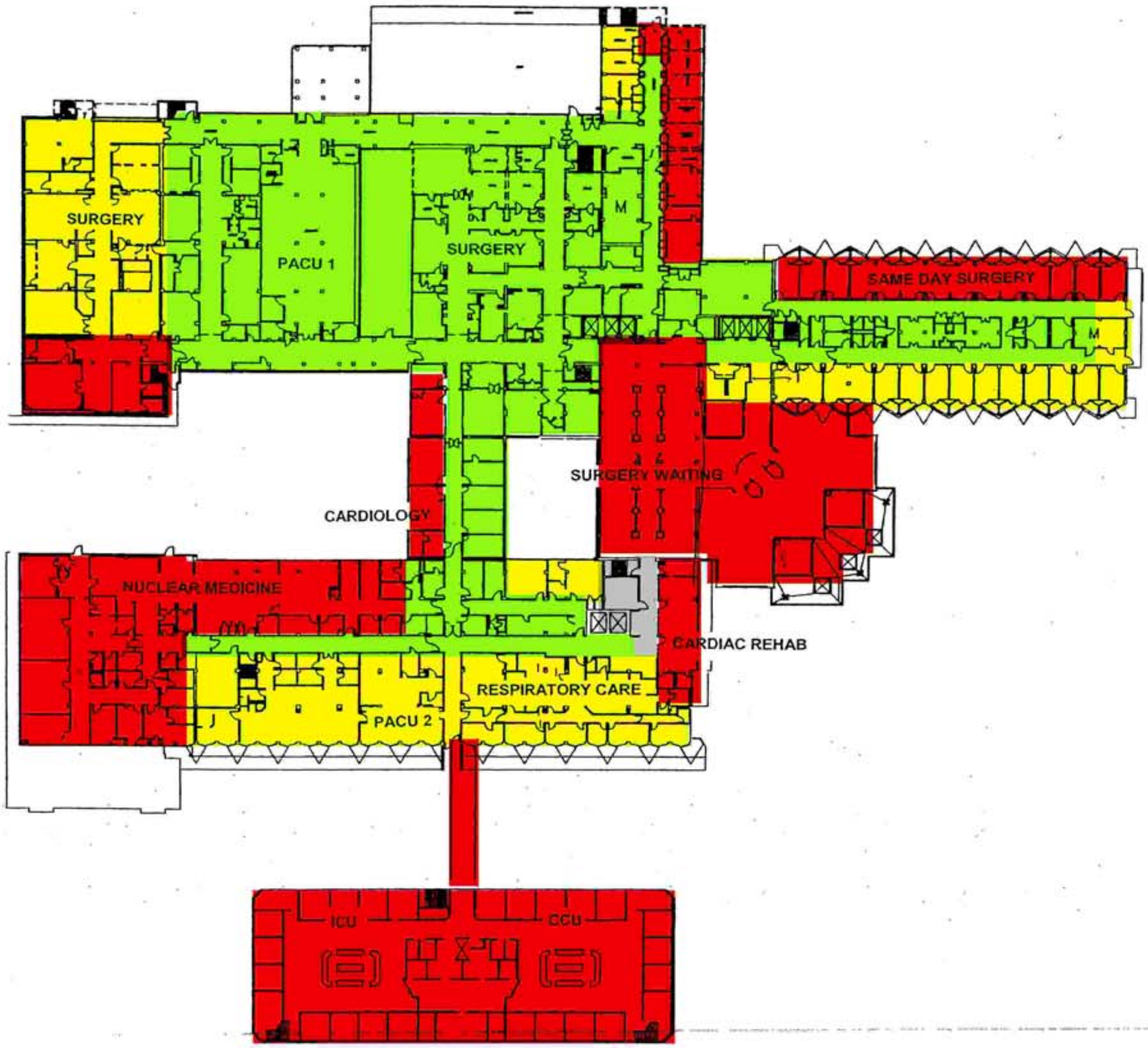
Secondary Shelter Area
(Moderate Hazard)

Walkways
For travel between shelter areas only-no loitering
(Moderate Hazard)

Do Not Use for Shelter
(High Hazard)

WIND 2
SHELTER PLAN

2nd Floor



Preferred Shelter Area
(Low Hazard)

Secondary Shelter Area
(Moderate Hazard)

Walkway
For travel between shelter areas
only-no loitering
(Moderate Hazard)

WIND 2
SHELTER PLAN

3rd Floor

Preferred Shelter Area
(Low Hazard)

Secondary Shelter Area
(Moderate Hazard)

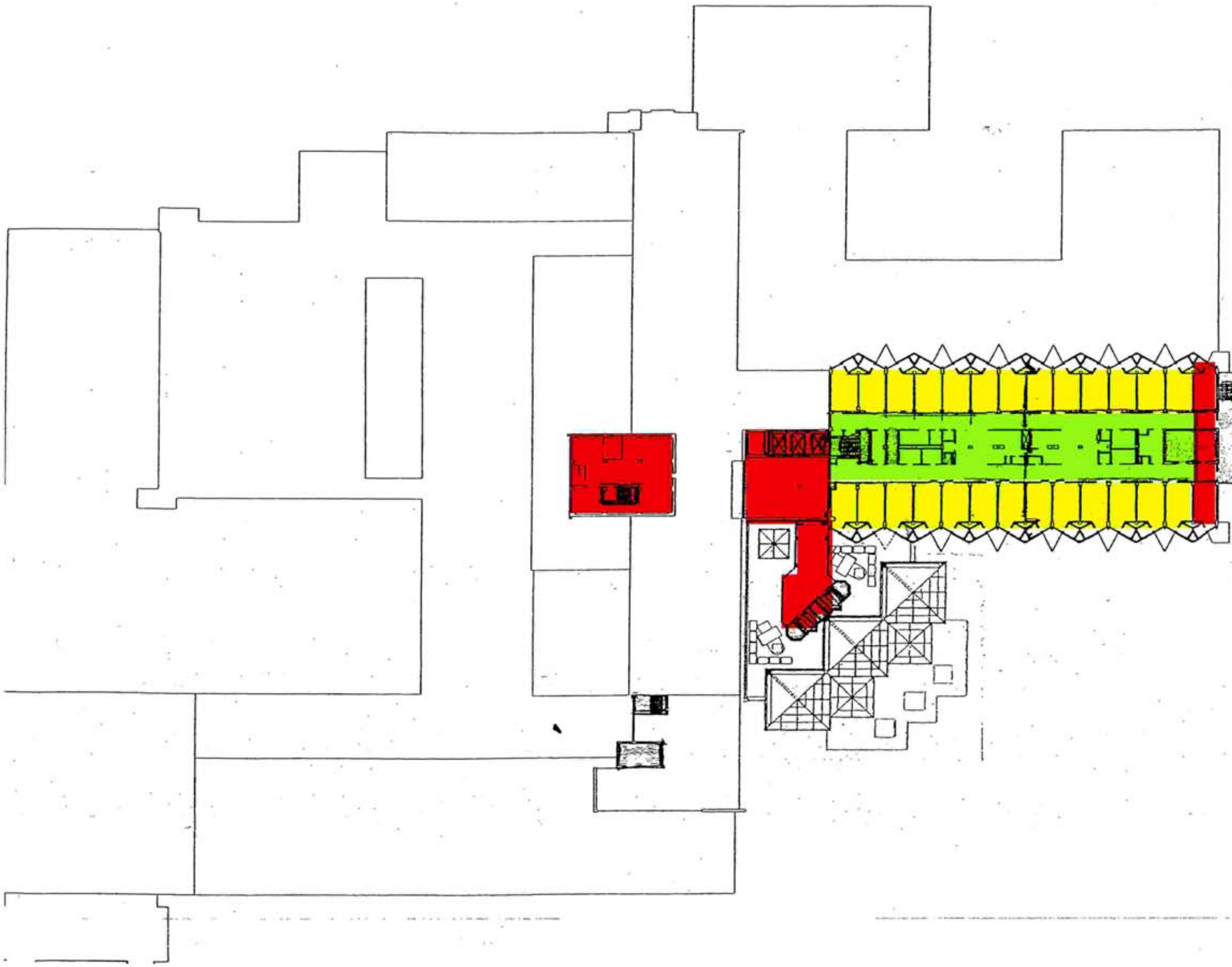
Walkway
For travel between shelter
areas only–no loitering
(Moderate Hazard)

WIND 2
SHELTER PLAN

4th Floor

WIND 2
SHELTER PLAN

5th Floor



Preferred Shelter Area
(Low Hazard)

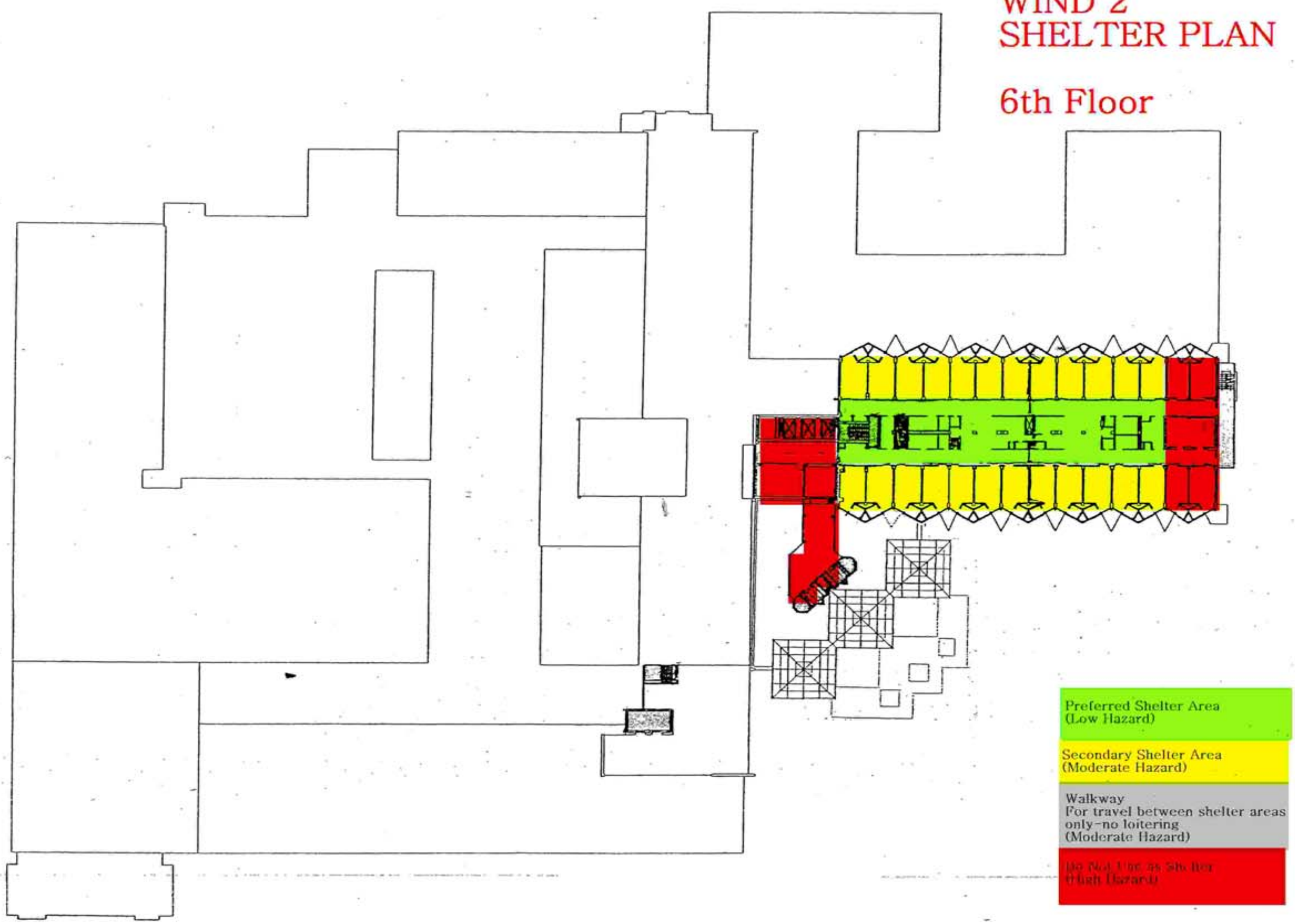
Secondary Shelter Area
(Moderate Hazard)

Walkway
For travel between shelter
areas-no loitering
(Moderate Hazard)

[illegible]

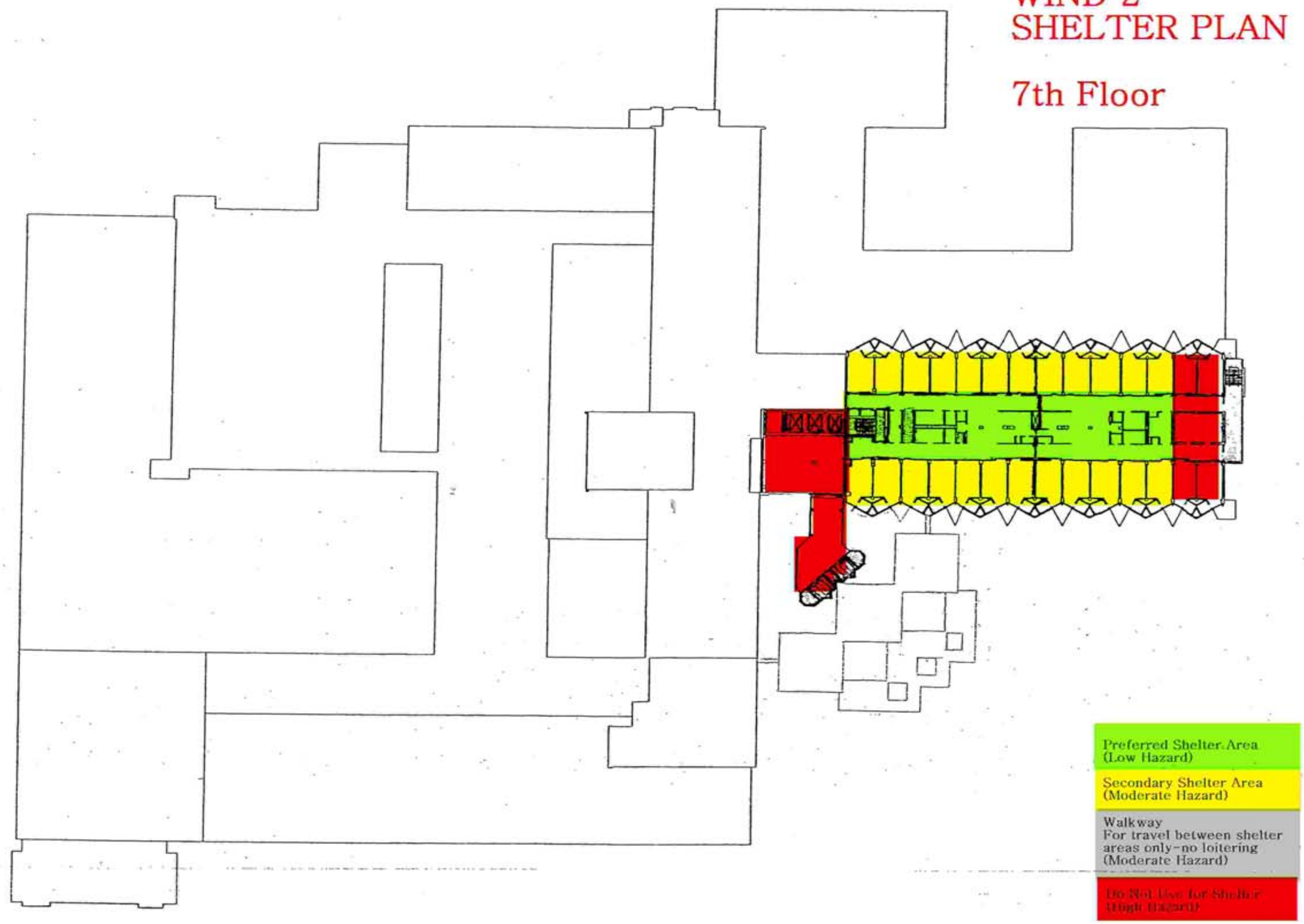
WIND 2
SHELTER PLAN

6th Floor



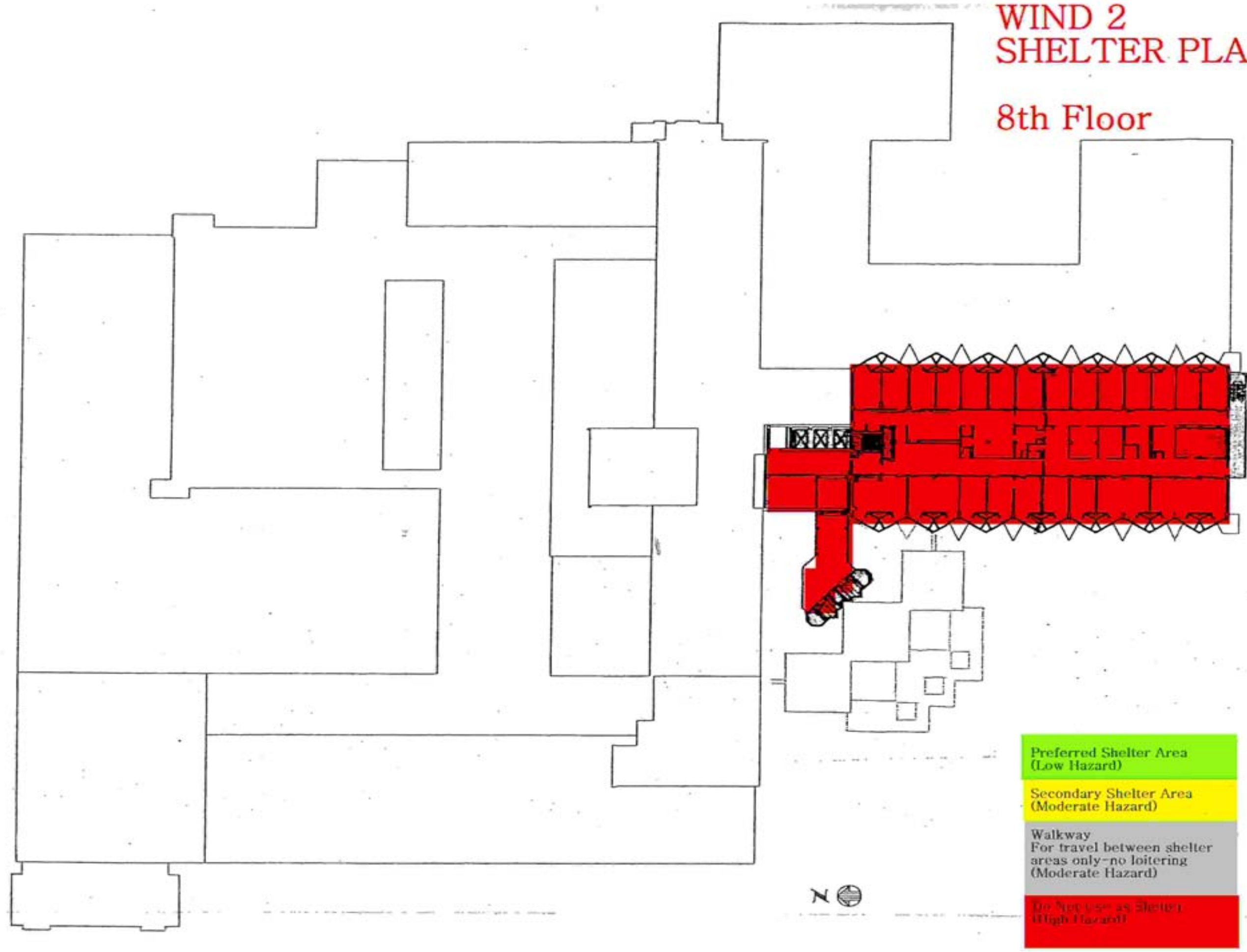
WIND 2 SHELTER PLAN

7th Floor



WIND 2 SHELTER PLAN

8th Floor



APPENDIX F2

DEFINITION OF TERMS
(Adapted from information on the National Hurricane Center Web Site)

ADVISORY:

Official information issued by National Hurricane Center describing hurricane watches and warnings in effect along with details concerning hurricane locations, intensity and movement, and precautions that should be taken. Advisories are also issued to describe:
(a) hurricanes prior to issuance of watches and warnings and
(b) tropical storms.

BEST TRACK:

A subjectively-smoothed representation of a hurricane's location and intensity over its lifetime. The best track contains the hurricane's latitude, longitude, maximum sustained surface winds, and minimum sea-level pressure at 6-hourly intervals. Best track positions and intensities, which are based on a post-storm assessment of all available data, may differ from values contained in storm advisories. They also generally will not reflect the erratic motion implied by connecting individual center fix positions.

DIRECT HIT:

A close approach of a hurricane to a particular location. For locations on the left-hand side of a hurricane's track (looking in the direction of motion), a direct hit occurs when the hurricane passes within a distance equal to the hurricane's radius of maximum wind . For locations on the right-hand side of the track, a direct hit occurs when the hurricane passes to within a distance equal to twice the radius of maximum wind. Compare indirect hit , strike .

EYE:

The roughly circular area of comparatively light winds that encompasses the center of a hurricane. The eye is either completely or partially surrounded by the eye wall cloud.

EYE WALL:

The area surrounding the "eye" of a hurricane where very intense winds are located.

EXPLOSIVE DEEPENING:

A decrease in the minimum sea-level pressure of a hurricane of 2.5 mb/hr for at least 12 hours or 5 mb/hr for at least six hours.

FLASH FLOOD WATCH:

A weather watch issued when there is a potential for flash flooding in a given area.

FLASH FLOOD WARNING:

A weather warning issued when a flash flood is imminent and immediate action is necessary.

HURRICANE:

Pronounced circulation with a constant wind speed of 74 mph or greater. Hurricanes can intensify to become major storms. They are rated on an intensity scale called the Saffir-Simpson scale.

HURRICANE LOCAL STATEMENT:

A weather statement issued by the National Weather Service which details a hurricanes potential impact on a local area.

HURRICANE SEASON:

The portion of the year having a relatively high incidence of hurricanes. The hurricane season in the Atlantic, Caribbean, and Gulf of Mexico runs from June 1 to November 30.

HURRICANE WATCH:

A weather watch issued for coastal areas when there is a threat of hurricane conditions within 24 to 36 hours.

HURRICANE WARNING:

A weather warning issued for coastal areas when there is a threat of hurricane force winds within 24 hours or less. A hurricane warning can remain in effect when dangerously high water or a combination of dangerously high water and exceptionally high waves continue, even though winds may be less than hurricane force.

INDIRECT HIT:

Generally refers to locations that do not experience a direct hit from a hurricane, but do experience hurricane force winds (either sustained or gusts) or tides of at least 4 feet above normal.

LANDFALL:

The intersection of the surface center of a hurricane with a coastline. Because the strongest winds in a hurricane are not located precisely at the center, it is possible for a hurricane's strongest winds to be experienced over land even if landfall does not occur. Similarly, it is possible for a hurricane to make landfall and have its strongest winds remain over the water. Compare direct hit, and indirect hit.

MAJOR HURRICANE:

A hurricane of Category 3 or higher on the Saffir-Simpson scale

MODELS:

Numerical computer models which attempt to forecast the state of the atmosphere and future storm intensity/movement.

PRESENT MOVEMENT:

The best estimate of the movement of the center of a hurricane at a given time and given position. This estimate does not reflect the short-period, small scale oscillations of the hurricane center.

RADIUS OF MAXIMUM WINDS:

The distance from the center of a tropical cyclone to the location of the cyclone's maximum winds. In well-developed hurricanes, the radius of maximum winds is generally found at the inner edge of the eyewall .

SAFFIR-SIMPSON SCALE:

A hurricane intensity scale which categorizes hurricanes on a scale of 1 to 5 according to the storm's wind speed, barometric pressure, storm surge and damage potential. Sustained wind speeds are defined as one-minute duration winds at 33' above open ocean

Saffir-Simpson Scale

Category	Sustained Wind Speed (mph)	Peak Gust (mph)	Storm Surge (ft)	Pressure (inches of Mercury)	Damage
1	74-95	94-120	0-5	28.94	Minimal
2	96-110	121-139	0-8	28.50 - 28.91	Moderate
3	111-130	140-164	0-12	27.91 - 28.47	Extensive
4	131-155	165-196	0-18	27.17 - 27.88	Extreme
5	>155	>196	0-18+	27.16	Catastrophic

STORM SURGE:

An abnormal rise of the sea along a shore as a result, primarily, of the high winds in a land falling storm. Storm surge is usually estimated by subtracting the normal or astronomic high tide from the observed storm tide.

STRIKE PROBABILITIES:

The chance, in percent, of a storm passing 50 miles to the right or 75 miles to the left of a given location. This is used to indicate the highest probability of landfall (location) for a hurricane.

TROPICAL WAVE OR EASTERLY WAVE:

A trough of low pressure in the trade-wind easterlies that can develop into a tropical disturbance.

TROPICAL DISTURBANCE:

A moving area of thunderstorms in the tropics that maintains its identity for 24 hours or more. This is a common phenomenon in the tropics. During the summer, these can develop into tropical depressions.

TROPICAL DEPRESSION:

A circulation at the surface in the tropics with a highest constant wind speed of 38 mph or less. A tropical depression is watched for possible development into a tropical storm.

TROPICAL STORM:

A distinct circulation with a wind speed of 39 to 74 mph. Tropical storms often develop further into hurricanes.

TROPICAL STORM WATCH:

A weather watch issued for coastal areas when there is a threat of tropical storm conditions within 24 to 36 hours.

TROPICAL STORM WARNING:

A weather warning issued for coastal areas when there is a threat of tropical storm force winds within 24 hours.

WIND SPEED CONVERSIONS

1 Knot = 1.15 miles per hour = .515 meters per second

APPENDIX G

MITIGATION REPORT

West Jefferson Medical Center Hurricane Mitigation Plan

Submitted by:

Principal Investigators

Dr. Marc Levitan

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levitan@hurricane.lsu.edu

And

James P. Gregg

Prepared for:

Dr. Walter Maestri, Jefferson Parish Emergency Management

West Jefferson Medical Center

LSU HURRICANE CENTER

Addressing Hurricanes and Other Hazards and Their Impacts on the Natural, Built, and Human Environments

G.1 INTRODUCTION

The intentions of this report are to provide West Jefferson Medical Center with an overview and recommendations for the eight-story south wing's use as a hurricane shelter. The recommendations are based upon wind tunnel studies conducted on the eight-story south wing with the surrounding facilities incorporated into the study for topographic purposes only. Proposals for additional medical center campus facility's capabilities to be used as a hurricane shelter are based on analysis and results from the eight-story south wing, along with current codes and guidelines.

Please refer to the technical report for detailed information on design pressures, and to the shelter report for suggested shelter areas.

G.2 WEST JEFFERSON MEDICAL CENTER

Beginning in the early 1960's, West Jefferson Medical Center was constructed in a series of phases, approximately fifty miles north and twenty miles north west of the Gulf of Mexico in Marrero, Louisiana. Over the years the hospital has grown into a campus that includes two, ten-story doctor's towers, an eight-story south wing, and various other interconnected facilities. Until the late 1970's, Walter Blessey, P.E., a local structural engineer, was the main designer for the hospital. During that period he designed and directed the construction of the eight-story south wing, which contains most of the main shelter areas. Contrary to the region, the hospital's ground floor is four feet above sea level and thus considered to be on high grounds.

G.2.1 Structural

The eight-story south wing is a reinforced concrete structure with a thirteen-foot tall first floor; seven, eleven-foot upper floors; and a ten-story mechanical tower. Above each of the front and rear windows on this structure, a small slab protrudes out from the exterior wall to provide a triangular shaped shade. Reinforced steel was continued from the interior slab into the extended, triangular shaped shade area providing required additional support strength. There is also a steel frame, glass atrium attached to the front, left side of the south wing.

G.2.3 Components and Cladding

The components and cladding consist of any member of the building that is not structural, e.g. windows, walls. The south wing windows have an aluminum frame with non-impact resistant $^{7}/_{32}$" annealed glass. Although film has been added to the windows, they are still not impact resistant (see Figure G.1). At the time of construction, the 1960 building code required all commercial windows have capabilities to withstand pressures of 20 pounds per square foot (psf). Mr. Blessey's intuition knew that 20 psf was not enough; therefore, he designed, specified, and tested each window for 40 psf. Impact resistant glass was seldom used in the 1960's due to lacking knowledge of hurricane forces, and was not used in any of the buildings Mr. Blessey designed and constructed for the hospital.

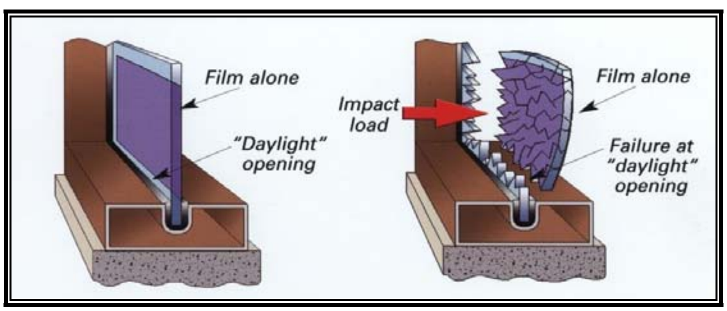

Figure G.1 - Example of laminated glass failure

G.2.3 Mechanical

Electricity and natural gas are the main sources of energy for the hospital. The electrical feed is provided by Entergy and is located to the rear of the eight-story south wing on a slab near the maintenance area. The boiler room is also located in this maintenance area and uses natural gas to create electricity for the main areas of the facility. There are also diesel back-up generators on ground level, near the main boilers.

G.3 HOSPITAL INTEGRITY

G3.1 Structural

Past hurricanes reveal that reinforced concrete structures normally do not suffer significant structural damage during a hurricane; therefore, the overall the structural integrity of the south wing is in good condition. However, the roof will receive high uplift pressures during high winds that can peal off even the strongest roof. Reviewing the structural plans, the roof of the south wing was designed the same as the rest of the floors, for live load as the main load. Under normal circumstances the girders that support the roof would have reinforcing steel in the bottom to provide the needed strength. However, with a high uplift pressure the loads will be reversed from what they were designed for requiring steel to be in the top. On the 16" girders there is a 7' section in the top without any reinforcing which must be checked.

G.3.2 Components and Cladding

A hurricane's high winds can jeopardize the building's envelope amid high pressures, large falling objects, and wind borne-debris. At design pressure, the window failure rate is 1% or 2-3 windows on the south wing, assuming the frames do not fail. Wind tunnel studies show that given a direct hit, category 2 hurricane scenario, the south wing will receive pressures greater than the original tested design pressure of 40 psf. ASTM standards allow the estimated probability of failure to increase from 1%, which is the normal design failure rate, to 5%. Determining probability of window failure due to design pressures greater than 5% is complex and inaccurate. Table G.1 lists window failures due to high pressures for different strength hurricanes. Overall, the corner and elevator areas will generally have the highest pressures and will have a highest probability of breaking due to pressure.

Table G.1 - Probability of Window Failure due to High Pressures

Eight-Story South Wing Windows Probability of failure due to pressures

<table>
<tr><th>Floor</th><th>Cat 1</th><th>Cat 2</th><th>Cat 3</th><th>Cat 4</th><th>Cat 5</th></tr>
<tr><td>1st</td><td rowspan="5">< 1 %</td><td rowspan="2">≈ 1 %</td><td rowspan="8" colspan="3">> 5 %</td></tr>
<tr><td>2nd</td></tr>
<tr><td>3rd</td><td rowspan="3">≈ 5 %</td></tr>
<tr><td>4th</td></tr>
<tr><td>5th</td></tr>
<tr><td>6th</td><td rowspan="3">≈ 1 %</td><td rowspan="3">> 5 %</td></tr>
<tr><td>7th</td></tr>
<tr><td>8th</td></tr>
</table>

Surrounding areas become compromised with the potential of large trees in the courtyard being blown down, the hazard of various unsecured objects being displaced about the facility, and the possibility of objects on top of the roof being lifted during a hurricane. Otherwise, there are not any large objects close enough to the facility to pose a threat of falling.

Numerous roofs in the hospital complex, as well as neighboring roofs, have gravel topping. Since the windows are not impact resistant, they will break when impacted by this topping and expose the structure to hurricane related elements. Unlike failure due to high pressures, all windows in the eight-story south wing that encounter wind-borne debris have the potential to fail. Ground floor windows generally have the highest probability of failure due to loose debris from neighboring areas. However, when comparing upper floor (2^{nd} –5^{th}) windows that are level with and face a gravel-topped roof to ground level windows, both are considered to have equal risk of breaking. Upper floor windows will also encounter loose debris and break, but the magnitude of wind borne debris will be much less than that which comes in contact with ground floor windows. Please refer to the shelter report to evaluate which upper floor windows are considered comparable risk to ground floor conditions.

Losing roof decking can cause water leaks, which could force an entire floor to be evacuated. The 8th floor south wing and ICU/ CCU buildings will lose either shingles or the entire roof thus allowing water to interrupt services and continuous care of patients.

G.3.3 Mechanical

Although there are current plans to raise the back-up generators to the second floor they still may not meet the maximum flood depth caused by potential storm surge. Also, all the control panels that distribute the power to the hospital are on ground level and will not function when wet. Therefore, it is expected there will not be any power as long as the control panels and back-up generators are below flood level.

Tables G.2a and G.2b list shelter areas and the reasons why they are considered high hazards as defined in the shelter report.

Table G.2a. Category 3 or greater High Hazard Shelter Areas per the Shelter Report

Shelter Area	Hazard
1st Floor	Flooding
2nd Floor	Flooding
8th Floor	Roof Uplift Pressures
ICU/ CCU	Roof Uplift Pressure/ Wind-borne debris

Table G.2b - Category 3 or greater High Hazard Shelter Areas

Shelter Area	Hazard
1st Floor	
Patient Registration	Wind-borne debris
Food Services	Wind-borne debris/ Lay down*
Elder Plus	Wind-borne debris/ Lay down*
South wing walkway	Wind-borne debris
Auditorium	Roof/ Lay down*
2nd Floor	
East side of Same Day Surgery Surgery waiting area Surgery (next to parking garage) Cardiology Nuclear Medicine Cardiac Rehab	Wind-borne debris
3rd Floor	
Telemetry Post Partum Nursery Delivery Offices Walkways	Wind-borne debris
4th Floor	
Medical Surgery Rehab Pediatrics Rehab Kitchen	Wind-borne debris
5th - 7th Floor	
Elevator Area windows	High External Pressures
Corner rooms	High Pressures
8th Floor	
Elevator Area windows Patient Rooms windows	High External Pressures

* Lay down due to trees

G.4 RECOMMENDATIONS

The hospital's exposure and vulnerability to destruction or even devastation is amplified when their commitment to saving lives and protecting their investment in sophisticated and specialized equipment is jeopardized. During hurricane Andrew, Mercy Hospital in Miami, Florida, received sustained winds of 115 mph and over 9 ft of storm surge that resulted in over $10 million in damage. Once wind-borne debris broke Mercy's windows, rain destroyed vital equipment and crippled the hospital's ability to function. One hospital manager estimated that the daily costs, measured in services lost (e.g., canceled surgeries), approached $1 million per day (FloridaDisaster.org).

A hospital planning to use its facilities as a shelter before, throughout, and after a hurricane must take precautions and make appropriate preparations to see that the facility has proper protection in place to withstand hurricane force winds and rising waters. Charlotte Regional Medical Center, Punta Gorda, Florida, was extensively damaged by hurricane Charley in 2004 and was forced to completely evacuate their patients and employees after portions of the roof were blown away and other parts were severely impaired. Once windows were broken, employees held up mattresses to protect patients from flying glass for duration of the hurricane (Surbaugh, 2004). Choosing not to utilize appropriate and necessary protection from hurricanes can jeopardize the occupants of the hospital during the hurricane; victims afterwards because adequate medical attention is unavailable; and additionally to the hospital's budget as it creates a large financial encumbrance.

G.4.1 Structural

With the top section subjected to tension and no reinforcing steel at mid span, once the applied moments are greater than the girders cracking moment it will fail. Completing a structural analysis with it was determined that the applied moment was greater than the cracking moment on a strong category five storm. Therefore, it is recommended that the eight floor not be used in a category five storm.

G.4.2 Components and Cladding

With the existing windows being under designed for hurricane pressures, some form of protection is needed. Replacing the windows with hurricane windows or installing storm shutters will protect windows and their cavity or possible opening. If no protection or a product that does not protect the window area from high pressures is used, then areas in yellow on the shelter report should be used with caution and be prepared to evacuate on notice if needed. The Table G.3 illustrates the difference between hurricane protection products and whether or not they can withstand hurricane pressures. All the products, except plywood, comply with ASTM E 1986 and 1996. If a product that is not listed in table G.3 is used, it must meet the above standards.

To protect the facilities from falling debris, it is recommended that any loose objects be secured, tied down, or completely removed before a storm. Trees should be trimmed to minimize damage in the event they should fall.

With windows being subjected to wind-borne debris, some type of protection is required. All the products listed in table G.3 provide some type of protection against wind-borne debris. In addition to protecting the windows, replacing all gravel roofs will reduce the amount of wind-borne debris during a hurricane.

Due to the roof gravel being within 1500 feet of the south wing, if the hospital was designed under the current code windows on the 6th floor and below on the west side, 4th floor on the east side of the south wing would have to be protected from flying debris.

G.4.3 Mechanical

Once flood levels exceed the back-up generators or control panels, the hospital will loose power. Currently, there are plans to raise the back-up generators to the second floor but no plans to move the control panels. Wiring a secondary control panel above the flood level from the back-up generator to the essential areas will avoid a long-term disruption in electricity.

G.4.4 Overview

The eight-story south wing has 287 windows, not including windows on the ninth and tenth floor mechanical tower. Installing most window protection will be difficult and costly. For floors two through eight, a lift or crane will be required in order to place the windows or shutters onto the building from the exterior. Old windows will have to be removed and roll down shutters will have to drill through ten inches of concrete. Based on estimates for the eight-story south wing, it will cost about $300,000 to install either new windows or roll down shutters.

Table G.3 - Hurricane Window Protection

Product	Brief Description	Fixed/ Permanent	Deployment Required	Installation Required	Storage	Can be Interior Mounted	Can Withstand High Pressures	Maintenance	Price per window (Materials Only)
Hurricane Windows	Remove and replace windows with windows	✓					✓	None	$1,000 - $2,500
Automatic Roll Down Shutters	Roll down shutter system attached to front of each window or opening	✓	✓			✓	✓	High	$2500 - $3,000
Manual Roll Down Shutters		✓	✓			✓	✓	High	$1,000 - $2,000
Accordion Shutter	Accordion shutters	✓	✓			✓	✓	Moderate	$700 - $1,000
Storm Panels	Clear Acrylic, Steel or Aluminum panels installed on a preset track			✓	✓	✓	✓	Moderate	$250 - $500
Fabric Screens	Fabric screens placed over window			✓	✓	✓		Low	$200 - $500
	Large screen			✓	✓			Low	$12 - $14 per sq. ft. +
Aluminum Screens	Metal screen over opening	✓				✓		Low	$1,500 - $1,800
Plywood	5/8" or 3/4" thick precut plywood shutters			✓	✓	✓		Low	$40 - $50

+ Includes Installation

G.4.5 Hurricane Resistant Windows

Hurricane resistant windows are normally layers of heat strengthened heat tempered or annealed glass with a layer of film between them (Appendix G1, Figure G1.1). The film layer extends outside the glass and is attached to a properly mounted frame. To comply with current standards, it is imperative the window frames are securely attached to the structure (Appendix G1, Figure G1.2).

With hurricane resistant windows in place, there is no need for deployment or subsequent installation before a hurricane. This will provide continuous protection throughout the life of the building from hurricanes, as well as tornados. Adding hurricane windows to an existing building will have the high initial cost, but one of the lowest long-term cost through energy efficiency and minimal maintenance. However, in order to maintain the capabilities to withstand high pressures related to a category 4 storm or greater, non-operable hurricane window should be used. Operable hurricane windows still provide protection against high pressures but not near same magnitude as fixed. At a strong category 4 storm operable windows will begin to pass the standard acceptable failure rate of 1 %.

G.4.6 Roll Down Shutters

Roll down shutters can be either mechanically or manually deployed. The ability to close the shutter from the inside makes them the most convenient type of shutter. A box containing a shutter is placed above each window and guided with a track when deployed (Appendix G1, Figures G1.3 & G1.4). As the hurricane approaches each shutter is deployed and left down until the hurricane completely passes. Mechanical shutters will reduce the time required to deploy, but with loss power they will operate the same as the manual shutter. Although roll down shutters are the strongest type of shutter, they only protect when deployed. Due to all the moving parts and operating on a track, roll down shutters are high maintenance. Mechanical shutters can cost about twice as much as the manual roll down shutters.

G.4.7 Accordion Shutters

Roll down shutter deploy vertically, where as accordion shutters deploy horizontally. The horizontal deployment allows one shutter to cover multiple windows that are in a row (Appendix G1, Figures G1.5 & G1.6). Accordion shutter will cost less than roll down shutters but have to be deployed from the exterior. For floors above ground level, exterior mounted accordion shutters are an impractical solution.

G.4.8 Storm Panels

Unlike roll down or accordion shutters, storm panels must be manually installed from the exterior on a pre-placed track. This can very labor intensive and only suggested for use in areas that can be easily reached. With the ability to choose acrylic, natural light will be able to enter the hospital (Appendix G1, Figures G.7 & G.8). Storm panels will have cheapest initial cost over all types of window protection meeting ASTM standards but their storage, maintenance of tracks, and installation per storm, will add to the long-term cost.

G.4.9 Large Fabric Screens

Shutters can be impractical for large openings, such as entrances, because they are cumbersome to close and open. Large fabric screens provide transparency, are lightweight, offer quick and easy installation, and provide equal protection against wind-borne debris (Appendix G1, Figures G1.9 – G.12). They are also a practical solution for areas that are too large to shutter or panel. The prefabricated screens are placed over the desired openings and fastened to hooks anchored in predrilled holes.

G.4.9 Aluminum Screens

Hurricane screens are aluminum screens attached in front of an existing window or door. They enhance architectural details without obstructing views. They also can be opened and closed for maintenance and emergencies. Hurricane screens protect existing window by repelling wind-borne debris. Hinged at the top or side, hurricane screens are capable of being operable or fixed (Appendix G1, Figures G1.13 – G1.15). Permanently attached, no deployment or installation is needed before a hurricane. Hurricane screens will also provide shade and are energy efficient.

Air is still allowed to flow through the screen, subjecting the existing window to high hurricane pressures. In the upper floors, corners and sides, where high pressures are a factor, permanent screens will not provide sufficient protection.

G.4.10 Fabric Screens

Fabric screens are thick PVC coated woven polyester fabric sheet placed over an opening to protect from wind-borne debris. Predrilled pins are lined up with slots in the fabric sheet allowing a quick and easy installation (Appendix G1, Figures G1.16 & G.17). As with the aluminum screens, fabric screens do not protect from high pressures.

G.4.11 Plywood

Although plywood does not comply with ASTM standards it is widely used because of cost and availability. If it is to be used as a temporary means of protection, the plywood must be precut and comply with the current International Building Code for plywood installation.

G.4.12 Other

Assuming the existing windows will break; sealed shutters can be placed from the interior instead of the exterior. With shutters on the inside of the building they will be easily accessible and time required to install and deploy will be lessened.

The above recommendations all comply fully or partially with ASTM standards. These standards are intended for protection of property instead of life safety. Since the hospital's primary goal is preserving life and safety, the integrity of the opening are more important than the windows themselves.

Table G.4 lists different shelter areas and some recommended types of shelter protection for those areas.

G.5 Mitigation Strategies

The intentions of table G.5 are to show some of the many different mitigation strategies for the eight-story south wing. *Mitigation 1*, hurricane windows, is an example of completely renovating the eight-story south wing with impact resistant windows. The cost will be the highest of the three methods but once in place hurricane windows will provide constant protection without affecting the aesthetics of the building. According to West Jefferson Medical Center maintenance, the existing windows in the south wing are breaking due to age and thermal stresses. Needing to replace the existing windows, using hurricane windows instead of laminated glass will avoid having to purchase new windows and some type of hurricane protection. Initial cost still may be high but with the energy savings, hurricane windows will pay for themselves over the years. During installation, mitigation 1 will require certain areas to be temporarily closed but with no deployment or storage necessary, mitigation 1 is the most convenient of the three allowing maintenance to focus on other tasks before a storm. Depending on the fire plan, operable windows can be replaced with fixed windows but in the event of loss of air conditioning operable windows provide a great means of ventilation.

Mitigation 2, hurricane shutters, can cost about the same as the hurricane windows or more depending on if they are manually or mechanically operated. Externally fixed in front of each window, manual roll down shutters can take hours to deploy and if not properly kept up may not deploy at all.

Mitigation 3, window screens and storm panels, will cut cost by using large fabric screens and storm panels where accessible. The ground floor windows, defined in hospital integrity section, can have Lexan clear storm panels and be installed without any scaffolding. To protect from wind-borne debris fixed aluminum screens are used for the upper and top floors. The aluminum screens do not protect from high pressures and some window failure is expected for a direct hit from a category 2 or greater (see hospital integrity section). The fixed aluminum screens do not require installation, the large fabric screens require minimal installation, where as, the storm panels are time consuming.

Table G.6 lists some of the hurricane window protection companies that were used in this report. To obtain a complete list of approved products the following two web locations are recommended.

Miami-Dade County approval list

http://www.miamidade.gov/buildingcode/pc-search_app.asp

Texas Department of Insurance

www.tdi.state.tx.us/company/wind/prod.indexshu.html

Miami-Dade County has set the standards in hurricane protection and any hurricane window protection used should be on their approval list. Although, majority of products on the Texas department of insurance site are Miami-Dade approved, the TDI site is more user friendly and not as overwhelming.

Table G.4 - Suggested window protection

Shelter Area	Hurricane Windows	Roll Down Shutters	Accordion Shutters	Storm Panels	Window Screens	Plywood
General						
1^{st} - 4^{th} floor atrium waiting areas			✓		✓	
East wing	✓	✓			✓	
Walkways	✓		✓			
West wing	✓	✓			✓	
South Wing Emergency Exits	✓	✓	✓	✓	✓	✓
1^{st} Floor						
1^{st} Floor South wing	✓	✓	✓	✓	✓	✓
Food Services	✓		✓		✓	✓
Education Classrooms	✓	✓	✓	✓	✓	✓
Maintenance	✓	✓	✓	✓	✓	✓
Cat Scan/ Pediatric Fast Track	✓		✓	✓	✓	✓
2^{nd} Floor						
2^{nd} - 7^{th} floor south wing	✓	✓			✓	
Cardiac Rehab	✓		✓		✓	
Nuclear Medicine	✓	✓	✓	✓	✓	✓
Cardiology	✓		✓	✓	✓	✓
ICU/ CCU	✓		✓		✓	
Same Day Surgery	✓	✓	✓	✓	✓	✓
Surgery (next to parking garage)	✓				✓	✓
3^{rd} Floor						
Delivery Offices	✓	✓				
Telemetry (facing east)	✓	✓	✓	✓	✓	✓
Nursery	✓	✓	✓	✓	✓	✓
4^{th} - 8^{th} Floor						
South Wing 4^{th} - 7^{th} corners, elevator area	✓	✓				
Rehab	✓	✓				
Rehab Kitchen	✓	✓	✓	✓	✓	✓

Table G.5a - Mitigation strategies for eight-story south wing

Floor	Area	Number of Windows	Window Size (in x in)	Mitigation 1	Mitigation 2*	Mitigation 3
1st	Front	32	60 x 138	Hurricane Glass	Roll Down Shutters	Storm Panels
	Cafeteria	17			Accordion Shutters	Large Fabric Screens
2nd	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens/ Storm Panels
	Emergency Exit	2	93 x 112			Large Fabric Screens
3rd	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
4th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
5th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
	Elevator area	7	46 x 114		Accordion Shutters	Aluminum Screens
6th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
	Elevator area	7	46 x 114		Accordion Shutters	Aluminum Screens
7th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
	Elevator area	7	46 x 114		Accordion Shutters	Aluminum Screens
8th	Front/Back	28	60 x 114		Roll Down Shutters	Aluminum Screens
	Emergency Exit	2	93 x 112			Large Fabric Screens
	Elevator area	7	46 x 114		Accordion Shutters	Aluminum Screens

*Based on manual roll down shutters

Table G.5b - Estimated Cost of Mitigation Strategies

	Price with installation	Advantages	Disadvantages
Mitigation 1	$600,000 - 1.1 million	Energy Efficient No Deployment Old windows need to be replaced anyways Aesthetically pleasing	Disruption for initial installation Cost Operable does not provide maximum protection
Mitigation 2	$570,000 - $900,000	Strongest Easy Deployment	High Maintenance Cost about the same as hurricane windows
Mitigation 3	$350,000 - $500,000	Cost Easy Installation No loss of service during installation	storage does not protect against high pressures

Table G.6 - Hurricane Protection Companies

Product	Company	Product Name	Web site	Location	Contact Info
Hurricane Windows	Pella Windows	Hurricane Shield	www.pella.com	New Orleans, LA	504-834-7744
	Dependable Glass	Safety Plus	www.depglass.com	Covington, LA	1-800-338-2414
	Al Broward	Window Lock	www.1800hurricane.com	Ft. Lauderdale, FL	1-800-487-7422
Storm Shutters	Roll A Way		www.roll-a-way.com	St. Petersburg, FL	1-800-683-9505
	Coulter Hurricane Products		www.coulterhurricane.com	Hialeah Gardens, FL	1-800-533-4869
	Rolling Shield		www.rollingshield.com	Miami, FL	1-305-436-6661
	Rolsafe		www.rolsafe.com	Ft. Myers, FL	1-800-833-5486
	Custom Pavers and Hurricane Shutters		www.custom-pavers.com	Ft. Lauderdale, FL	1-954-771-8090
	Sentinel Storm Protection		www.napleshurricaneshutters.com	Naples, FL	1-239-596-9697
	AGI Group		www.stormshutters.com	Sarasota, FL	1-800-823-6677
Fabric Screens	Wayne-Dalton Corp	Fabric Shield	www.wayne-dalton.com	Pensacola, FL	1888-827-3667
Aluminum Screen	Phoenix	SureGuard	www.1800hurricane.com	Ft. Lauderdale, FL	1-800-487-7422
	Exeter	Storm Shield Barrier	www.stormshield.net	Palm City, FL	1-888-393-8373
Large Screen	Storm Catcher	Strom Catcher	www.stormcather.com		1-888-962-7283
	Savannah Sales	Armor Screen	www.hurricaneproducts.com		1-888-640-0850
	Hendee Enterprises, Inc	Force 12	www.foce12protection.com	Houston, TX	1-713-796-2322

APPENDIX G1

HURRICANE WINDOWS

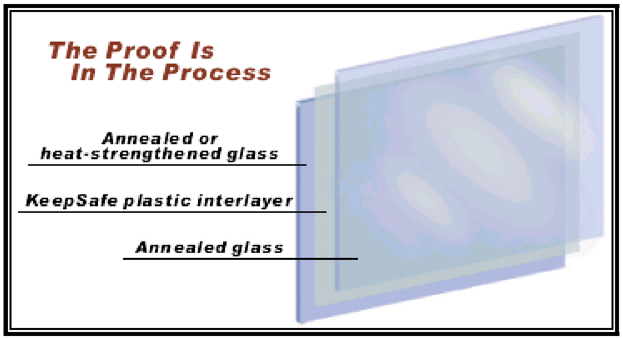

Figure G1.1 - Hurricane Window Layering (Gulf Cost Windows)

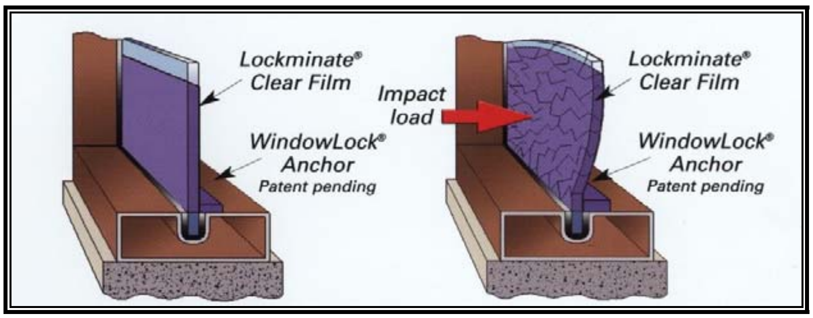

Figure G1.2 - Proper anchoring for hurricane glass (WindowLock)

Roll Down and Accordion Shutters

Figure G1.3 - Roll down and accordion shutters (Al Broward)

Figure G1.4 - Roll Down Shutters (Picture provided by NOAA)

Figure G1.5 - Accordion Shutters (Al Broward)

Figure G1.6 - Accordion Shutters (Custom Pavers & Hurricane Shutters)

Storm Panels

Figure G1.7 - Clear storm panels
 (Clear Guard)

Figure G1.8 - Clear storm panels (Clear Guard)

Large Screens

Figure G1.9 - Large installed hurricane screen (Screen Catcher)

Figure G1.10 - Large installed hurricane screen (Force 12)

Figure G1.11 - Anchoring of large screens (Screen Catcher)

Figure G1.12 - Storage of large screens (Force 12)

Aluminum Screens

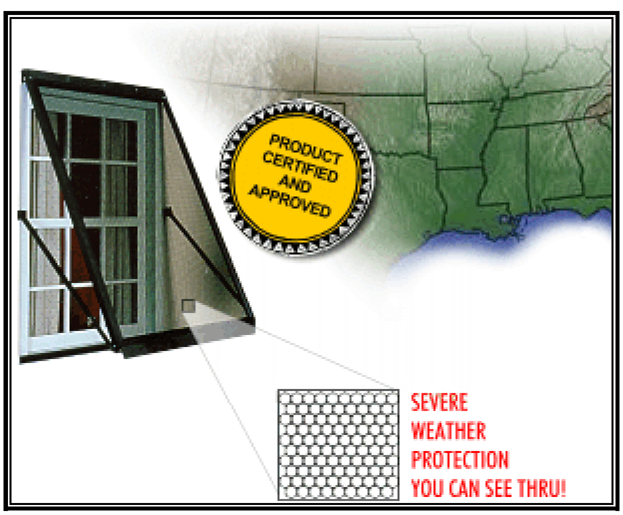

Figure G1.13 - Operable aluminum screen (Storm Shield)

Figure G1.14 - Fixed aluminum screens (Storm Shield)

Figure G1.15 - Installation of aluminum screens (Storm Shield)

Fabric Screens

Figure G1.16 - Illustration of fabric screen (Fabric-Shield)

Figure G1.17 - Installation of fabric screens (Fabric-Shield)

VITA

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